RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*):

2010 ANNUAL REPORT

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Erratum: Table 7 was corrected and replaced on 10 June 2013.

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The original design for this project and considerations for optimizing it based on new information and experience were first set out in Anderson and Burnham (1996) and Anderson et al. (2001). Estimation methods were further refined during a 2008 workshop for distance sampling held by S. Buckland, L. Thomas, T. Marques, E. Rexstad, and D. Harris in Marshall, California.

Personnel from Kiva Biological Consulting (California) led by I. Daly, from the Institute for Wildlife Studies (California and Nevada) led by J. Young, and from the Great Basin Institute (Nevada, Arizona, and the Beaver Dam Slope of Utah) led by T. Christopher conducted the field surveys. The field monitors from these teams and from Joshua Tree National Park who did the hard work of collecting and verifying the data were: P. Aplin, L. Baierl, L. Baltic, T. Bartels, M. Bassett, S. Boisvert, D. Buchner, A. Carlson, S. Carlton, H. Converse, C. Conway, I. Daly, E. Davis, J. Dear, A. d'Epremesnil, R.J. DePond, A. Devens, K. Dutcher, S. Dykman, K. Foley, M. Fossum, S. Fritts, P. Fuchs, C. Giuliano, C. Glassbrenner, K. Goodale, D. Halbruner, P. Havlik, J. Helvey, K. Holcomb, J. Houck, M.-E. Jacques, D. Kaleta, S. Karinen, L. Keener-Eck, D. Kent, G. Keyes, C. Klehm, K. Lalumiere, W. Lee, S. Lillie, P. Livingston, T. Magart, E. Mastrelli, C. McClurg, O. Miano, N. Mikle, L. Mjos, B. Nieto, B. O'Brien, T. Ose, J. Reilly, T. Rodgers, K. Rohling, S. Root, A. Salonikios, K. Schmidt, K. Shelp, B. Sparks, A. Steeley, S. Treu, C. Truettner, R. Vaghini, A. Wiley, N. Wiley, K. Yasuda.

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EXECUTIVE SUMMARY

The recovery program for desert tortoises in the Mojave and Colorado deserts (USFWS, 2011) requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units increase for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again from 2007 through 2010, desert tortoise populations in 5 of the 6 recovery units have been part of a coordinated, range-wide monitoring program using line distance sampling. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources (McLuckie et al., 2012).) The first 5 years of monitoring culminated in a summary report (USFWS, 2006) that included eleven recommendations, seven of which were tied to functioning of the monitoring program and are paraphrased here:

1. The range-wide monitoring program should continue under a formal study plan subject to scientific review.
2. Refine [line distance sampling] techniques to improve sampling efficiency and estimates of trends.
3. Evaluate the spatial scale of the monitoring program.
4. Improve training lines.
5. Evaluate the use of independent field teams to improve data consistency and quality.
6. Refine and formalize/document the QA/QC process.
7. Identify and assess options for securing continued funding for range-wide population monitoring.

This report describes the full set of quality assurance steps and final results for the 2010 monitoring effort. The above issues continue to drive review and improvement of the program, so that reporting also addresses these aspects of the annual effort. The range-wide monitoring effort is directed each year at 15 strata that will be used to describe long-term trends. Data were collected on transects by field personnel working with three different groups, Kiva Biological (18 personnel), the Institute for Wildlife Studies (15 personnel), and Great Basin Institute (30 personnel). Four personnel from Joshua Tree National Park also collected telemetry data in the Park. After an intensive, 12-day specialized training session, crews completed 878 transects (9401km) between 22 March and 28 May. In the course of these surveys, they reported 540 live tortoises.

Training is provided each year so that field crews are familiar with the specifics of distance sampling. Training also ensures consistency between the many crews collecting data. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the USFWS. Crews were passed after demonstrating appropriate detection

patterns (including detection proportion on the transect line), measurement accuracy from tortoise models to the transect line, and other skills. Two of the teams passed after retesting with a different partner.

Four parameter estimates contribute to final reported tortoise densities in each monitoring stratum. The basis for distance sampling is the estimation of the number of tortoises detected at increasing distances from the walked transect. As surveyors look farther from the transect centerline, they will detect fewer and fewer of the tortoises that are actually there, so describing the way detections decrease with distance allows for estimation of the proportion that were present but not detected within a given distance of the centerline. Second, an estimate is made of the proportion above ground or visible in their burrows and available to be detected on transects. Third, the first two estimates are combined with the number of tortoises encountered per kilometer walked to provide the actual density in each stratum. Finally, the proportion detected on the line must be estimated. Unless all tortoises were detected on the centerline, the density estimate must be adjusted to account for the occurrence of these additional tortoises.

Separate detection curves were used to describe the decreasing ability of each team to see tortoises that were farther from the walked transect line. These detection curves will capture any differences between teams in application of the protocol, but are mostly expected to reflect the terrain as well as the extent to which vegetation obscures the view in different parts of the range, since the curves account for tortoises that were present in the same area but not seen. In the southern part of the range, Kiva crews detected 67% of tortoises within 8 m of the transect centerline, and 58% out to 12 m from the line in the northern area that they sampled. GBI detected 41% out to 16 m, and IWS detected 59% to 14 m. The proportion of tortoises that were visible to be counted (G_0) varied in different parts of the range, which were surveyed at different times during the spring season. Visibility was as high as 96% in the Superior-Cronese telemetry site during the last 2 weeks of April. The lowest visibility was measured at 77% at the Gold Butte telemetry site, also monitored during the first 2 weeks of April. On average, crews walked 23 km for each tortoise that was observed, but this number varied considerably between monitoring strata. Although densities in the Northeastern Mojave Recovery Unit had been estimated at less than 2/km^2 in previous years, the density was estimated at 3.2 tortoises/km^2 this year, similar to 2009. The Western and Eastern Mojave recovery units also had densities under 4/km^2, whereas the 2 recovery units in the Colorado Desert measured at 4.2/km^2 (Northern Colorado) and 5.7/km^2 (Eastern Colorado). Within the Eastern Colorado Recovery Unit, the BLM areas had a density of only 3.7/km^2, whereas we estimated the density of tortoises on CMAGR at 13.8 tortoises/km^2. The Fenner and Ord-Rodman CHUs also had notably high density estimates at 6.9 and 7.5 tortoises/km^2, respectively. This pattern of higher densities in these 3 monitoring strata has been fairly consistent over the years.

To enable field crews to complete transects in previously unsampled areas within strata, a set of guidelines was implemented in 2008 and 2009 for modifying transects in areas with rugged terrain or other obstacles (USFWS 2012). These rules did enable crews to sample entire strata in a more representative way; however, in areas of California with lower funding, the resulting substrata never had enough transects or tortoise observations to separately evaluate tortoise densities in flat compared to rugged terrain. For this reason, in 2010, all transects in all recovery units except the Northeastern Mojave were to be completed to the extent possible along the original 12 km path. Mountainous terrain in the path was circumnavigated without searching for tortoises, and the path was resumed when possible. This method keeps transects in representative areas and also allows the proportion of unwalkable terrain to be estimated. The proportion of kilometers actually walked under this new method matched the expected number of kilometers based on the earlier modified-transect protocols.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. Results from earlier years of this project illustrated clearly that sufficient effort (transects) in each stratum is needed to encounter several tortoises, otherwise estimates are not possible. In 2010, funding enabled estimation of tortoise densities in all strata to at least a minimum extent, better than any year since 2005. Effective implementation of this program requires stable funding so that monitoring effort matches planning requirements rather than funding limitations.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2010

INTRODUCTION

The Mojave Desert population of the desert tortoise (*Gopherus agassizii*) was listed as threatened under the Endangered Species Act in 1990. This group of desert tortoises north and west of the Colorado River are now recognized as the species *G. agassizii*, separate from *G. morafkai* south and east of the Colorado River (Murphy et al., 2011). The original (USFWS, 1994) and revised recovery plan (USFWS, 2011) designate recovery units to which decisions about continued listing status should be applied. Because the 2010 monitoring effort preceded the revised recovery plan, data records were associated with the original recovery units so results reported here also use those recovery units. The recovery plan specifies that consideration of delisting should only proceed when populations in each recovery unit have increased for at least one tortoise generation (25 years), and the only means to determine trend is by a rigorous program of long-term monitoring. Before the tortoise was listed, populations were monitored either using strip transects (Luckenbach, 1982) where indications of tortoise presence (live or dead tortoises, scats, burrows, or tracks) were converted to tortoise abundance categories based on calibration transects conducted in areas of better-known tortoise density, or by using capture-recapture population estimates on a limited number of (usually) 1-mi^2 study plots (Berry and Nicholson, 1984). Although data have continued to be collected on transects and study plots in recent years, these methods suffer statistical deficiencies and/or logistical constraints that render them unsuited for monitoring trends in abundance applicable to entire recovery units (Corn, 1994; Anderson et al., 2001; Tracy et al., 2004). In 1999 the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) for estimating range-wide desert tortoise density.

Distance sampling methods use measurements taken from the center of the transect lines to tortoises to model detection as a function of distance from the walked path; tortoises farther from the travelled path have a lower probability of detection. In order to anchor the curve and estimate the true (not relative) proportion of tortoises detection within a given distance from the center of the transect, all tortoises must be detected on the transect centerline (Anderson et al., 2001; Buckland et al., 2001). There are additional assumptions in distance analysis – that distance is measured to the point where the animal was first detected and that distance is measured accurately – but these are easily satisfied in line distance sampling of desert tortoises. The assumption that detection at the centerline of the transect is perfect, however, can be violated during line distance sampling of tortoises, but the use of two observers minimizes the probability that tortoises are missed on the centerline and provides a correction factor in the form of an estimate of the number of tortoises on the line that were missed (USFWS, 2009).

Distance methods have been applied to estimate abundance of Sonoran Desert Tortoises (*G. morafkai*) since 2000 (Swann et al., 2002; Averill-Murray and Averill-Murray, 2005) and for *G. agassizii* in the Upper Virgin River Recovery Unit in Utah since a pilot study in 1997 (McLuckie et al., 2012). The USFWS used line distance sampling to estimate abundance of tortoises in the remaining five recovery units for *G. agassizii* in Utah, Arizona, Nevada, and California starting in 2001 (USFWS 2006, 2009, and 2012). This report includes results of training exercises for field crews, describes implementation of monitoring in 2010, and presents the analysis of desert tortoise density in 2010.

METHODS

Study areas and transect locations

Long-term monitoring strata (Fig. 1) will be used over the life of the project to describe population trends in areas managed to conserve tortoises ("tortoise conservation areas," TCAs). Generally each critical habitat unit (CHU) is treated as one monitoring stratum, although the portion of Mormon Mesa CHU that is associated with Coyote Springs Valley is treated as a separate stratum. Chuckwalla CHU is also treated as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Aerial Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). The Piute and Eldorado Valleys are currently treated as one monitoring stratum although they are in different recovery units. The Joshua Tree stratum does not encompass all suitable habitat for desert tortoises in Joshua Tree National Park (JTNP). The national park designation and current boundaries just post-date the designation of CHUs, so some of the Pinto Mountains and Chuckwalla CHUs (and monitoring strata) are in the current JTNP.

The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit (Anderson and Burnham, 1996). Power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the period of time (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years).

The magnitude of the population trend is a function of recovery activities and the population dynamics of the tortoise – neither of these elements are affected by monitoring design and sample size. The second contributor to the power to detect a trend – the level of background variability in the density estimates – is directly affected by the number, length, and placement of transects in the monitoring strata. Anderson and Burnham (1996) recommended that transect number and length be chosen to target precision reflected in a coefficient of variation (CV) of 10-15% for the estimate of importance (here, density for tortoise conservation areas in each recovery unit). The CV describes the standard deviation (a measure of variability) as a

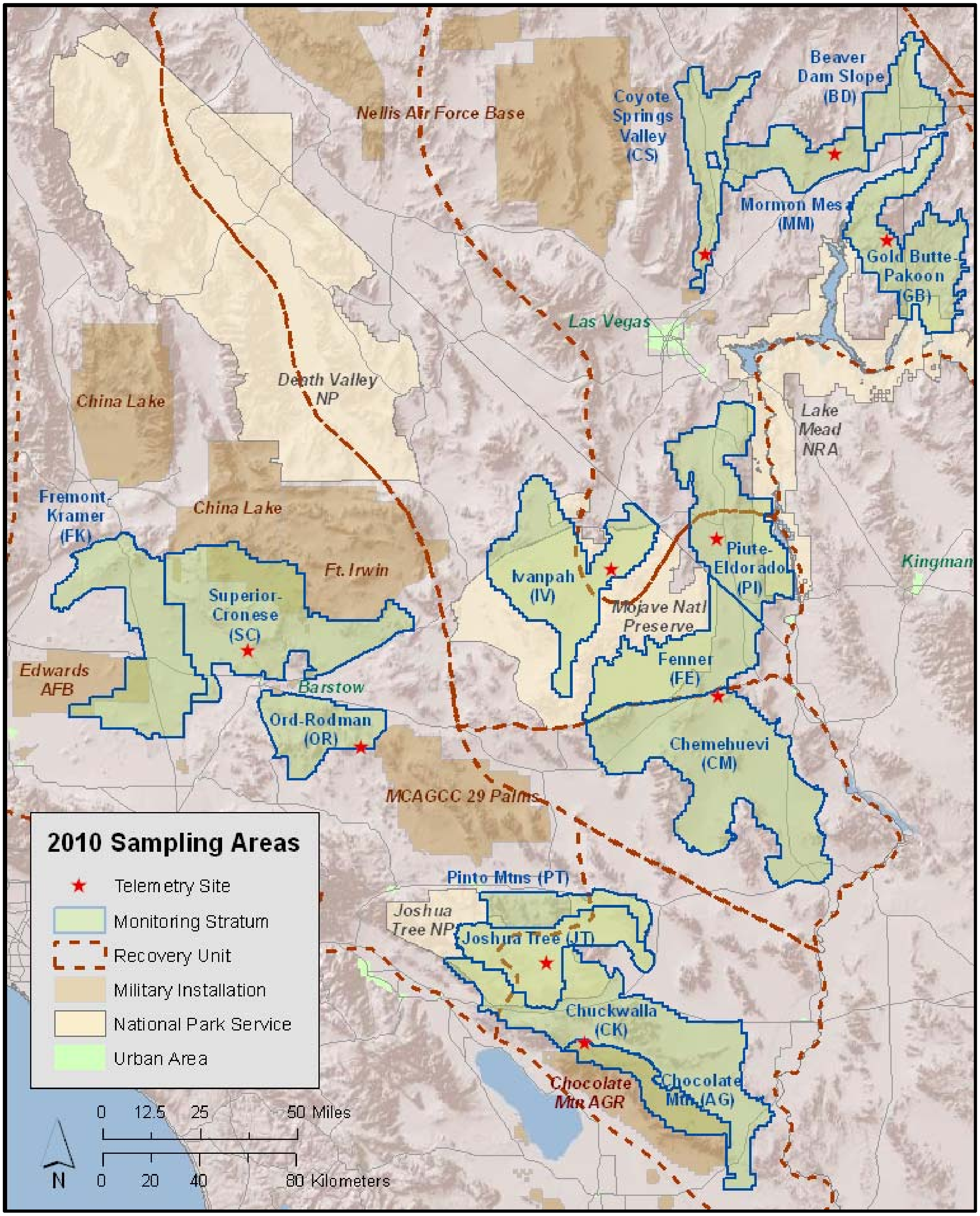

Figure 1. Sampled areas 2010.

proportion of the mean and is often converted to a percentage. Since recovery criteria target trends within recovery units (USFWS, 1994 and 2011), precision in that density estimate was the focus. The target CV is achieved based on the number of tortoises that might be encountered there (some strata currently have higher densities than others), as well as the area of the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al., 2001).

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice of transects. In strata with more assigned transects, nested lattices with smaller spacing (3 km) were used to ensure sufficient transects. In strata with fewer transects, lattices 9 km spacing were used. Systematic placement provides more even coverage of the entire stratum, something that may not occur when strictly random placement of transects is used. In both cases, transects are located at random with respect to the location of desert tortoises.

Transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises emerge from deep within shelters (burrows) from mid-March through mid-May and then again (less predictably) in the fall. These periods coincide with flowering of their preferred food plants (in spring) and with annual mating cycles (in fall). The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

During this season, not all tortoises are above ground or visible in burrows. To encounter as many tortoises as possible, monitoring is scheduled for early in the day and to be completed before the hottest time of day. Because tortoises are located visually, monitoring is restricted to daylight hours. Based on past experience, we expect tortoises to become most active after 7am at the beginning of April (it is usually too cool before this time), but to emerge earlier and earlier until their optimal activity period includes sunrise by the beginning of May. In May, we also expect daytime temperatures to limit tortoise above-ground activity as the morning progresses to afternoon.

Field crews complete transects during this optimal period each day. Start times are decided a week in advance, so crews arrive at transects at similar times on a given morning. However, completion times will be more variable, as a consequence of terrain, air temperature, number of tortoises encountered, etc. Under normal conditions, each team walked one 12 km square transect each day. Teams were comprised of 2 field personnel who switched lead and follow positions at each corner of each transect, so they each spent an equal amount of time in the leader and follower positions. The leader walked on the designated compass bearing while pulling a 25 m length of durable cord; the walked path is also the transect centerline and was indicated by the location of the cord. The length of cord also spaced the two independent observers, guiding the path of the follower; when the cord was placed on the ground after a tortoise or carcass was detected, it facilitated measurement of the local transect bearing. The walked length of each transect was calculated as the straight-line distance between GPS point coordinates that were recorded at 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed.

Both leader and follower scanned for tortoises independently without leaving the centerline, and the role of the crew member finding each tortoise was recorded in the data. Although the leader saw most of the tortoises, the role of the follower was to see any remaining tortoises near the centerline, so the follower role is crucial to unbiased estimation of tortoise densities.

Distance sampling requires that distance from the transect centerline to tortoises is measured accurately. When a tortoise was observed, crews 1) used a compass to determine the local transect bearing based on the orientation of the 25 m centerline, 2) used a compass to determine the bearing from the point of observation to the tortoise, and 3) used a measuring tape to determine the distance from the observer to the tortoise. These data are sufficient to calculate the perpendicular distance from the observed tortoise to the local transect line. If the tortoise was outside of a burrow, was handled enough to take mass and midline carapace length (MCL), to determine its sex, and to apply a small numbered tag to one scute. If a tortoise could not be measured because it was in a burrow, because temperatures precluded handling, or for any other reason, crews attempted to establish by other means whether the animal was larger than 180 mm MCL, the criterion for including animals in density estimates.

Because transects are 3 km on one side, it is not unusual for that path to cross through varied terrain or even be blocked by an obstacle such as an interstate highway. In the first years of this program, smaller transects in inconvenient locations were shifted or replaced, but this compromised the representative nature of the sample. Since 2007, the basic rules for modifying transects involve 1) reflecting or elongating transects to avoid obstacles associated with human infrastructure (large roads, private inholdings, etc.), or 2) shortening transects in rugged terrain. Substrate and access to transects can also make it difficult to complete transects during the optimal period of times, so 3) transects could be shortened to enable completion before 4 pm each day.

In 2008 and 2009, the rules for shortening transects were made more restrictive. Crews had the option to complete transects that were 12 km long (in low-relief terrain) or 6 km long (where higher-relief terrain precluded completion of 12 km in a working day). In the latter case, to avoid crews selecting particular terrain, the only way to shorten the transect was to walk it in the southwestern quadrant of the intended 12 km square. If the southwestern quadrant was judged too rugged to be completed safely by transect walkers, the final option was to not complete the transect at all. As in previous years, unwalked transects were replaced from the list of alternates. More situations were anticipated by additional rules in 2010, as described below.

Modification of previous procedures
After the 2009 field season, it was clear that funding uncertainties in California meant that sufficient transects might not be completed in order to substratify analyses for 12 km and 6 km transects. However, substratification continued to hold promise for analyses in the Northeastern Mojave Recovery Unit. In 2010, the same option to shorten transects to 6 km in rugged terrain were made available to GBI crews. However, IWS and Kiva crews shortened transects by following as much of the planned 12 km route as was possible. If it was anticipated that fewer than 4 km could be walked, the transect should be replaced instead with a transect from the alternate list. Instead of estimating the proportion of the area that is unwalkable based on the proportion of transects that were unwalkable, we would use the proportion of total planned kilometers (12 X number of planned transects) that were unwalkable.

In addition, transects that crossed stratum boundaries into public lands had previously been walked as planned (squares). Although this added sampling just outside the stratum, it seemed reasonable to assume the land management and tortoise fate would be similar on each side of the invisible boundary. Walking in a square is also less likely to introduce other problems compared to reflecting the transect. Nonetheless, starting in 2010, the protocol used to modify transects that intersected private lands or interstates since 2007 was applied to the portion of any transect that crossed out of monitoring strata, reflecting that portion into the stratum. Whether the segments of those transects outside the boundaries were walked outside the stratum or as a mirror image inside the stratum, the same length of transect is walked at the same distance from the stratum boundary, avoiding undersampling of areas on stratum boundaries (Figure 2). The impetus for this change was the recent large scale development and construction on public lands, often just along the borders of critical habitat, especially for renewable energy facilities and transmission lines. Since the monitoring program was initiated, other activities that are incompatible with tortoise conservation have become more common on public lands immediately adjacent to TCAs.

Specifics of how transect paths were to be modified for rugged terrain (shortened) or for administrative boundaries (reflected) can be found in the *2010 Desert Tortoise Monitoring Handbook* (USFWS 2010).

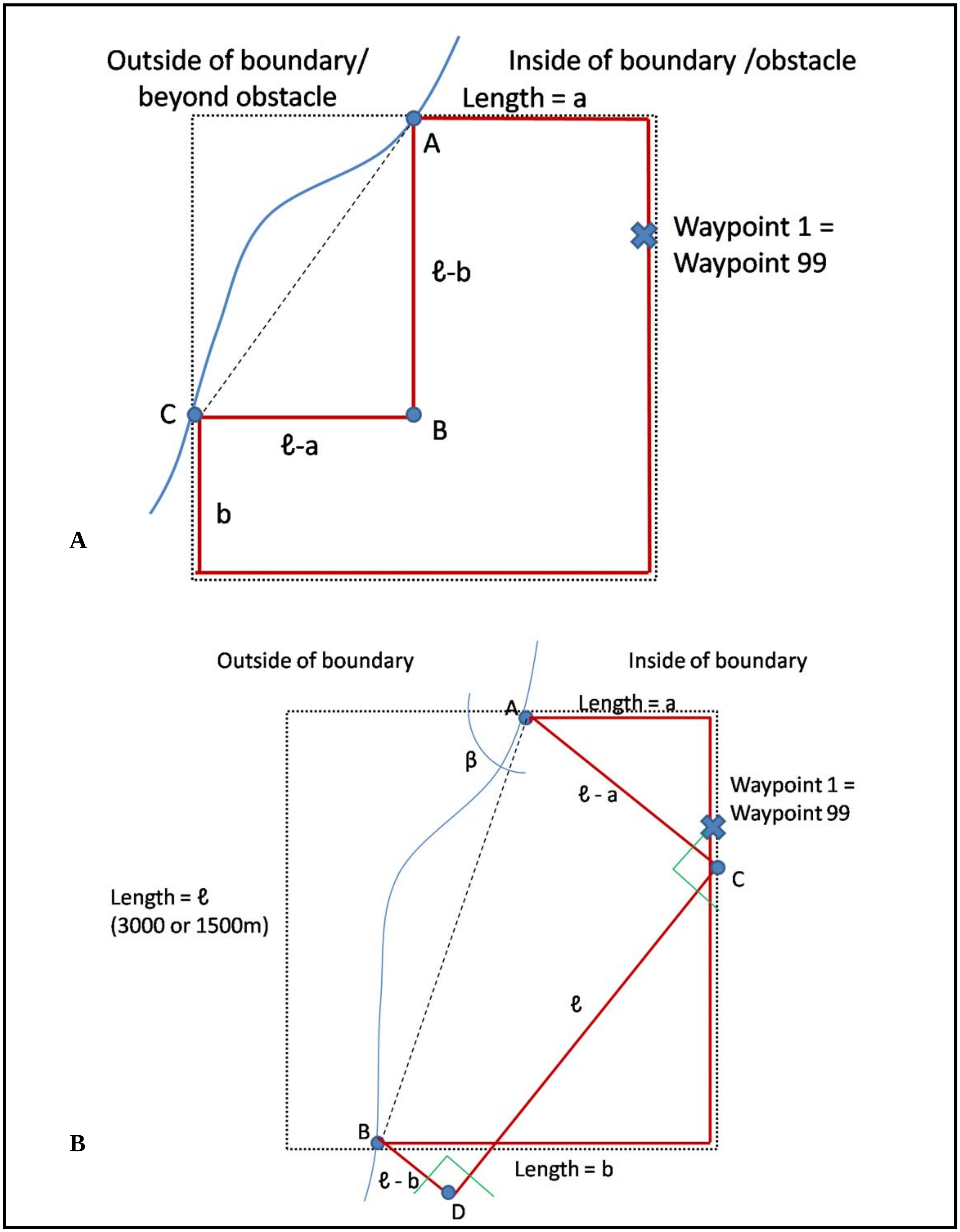

Figure 2. Planned (dotted lines) and reflected transect paths at administrative boundaries, now also applied to stratum edges. A) One-corner reflection. B) Two-corner reflection.

Proportion of tortoises available for detection by line distance sampling, G_0

Although we have general expectations about when tortoises are most active each day, and plan our sampling to match the best season and time of day, the fact remains that basing our density estimates only on the tortoises that are visible will result in density estimates that are consistently underestimated (biased low). Instead, we use telemetry to estimate the proportion of tortoises available for sampling, G_0 (“gee-sub-zero”), which is incorporated in the equation for estimating tortoise density and to correct this bias.

Telemetry allows us to locate radio-equipped tortoises that are as well as those that are otherwise undetectable in deep burrows or well hidden in dense vegetation. To quantify the proportion that were available for detection (“visible”) in 2010, telemetry technicians used a VHF radio receiver and directional antenna to locate 8-12 radio-equipped G_0 tortoises in each of 10 sites throughout the Mojave and Colorado deserts (Fig. 1). Each time a transmittered tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each tortoise on each day it was located. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, the G_0 estimate was calculated as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in PASW Statistics (release 18.0.2; SPSS, Inc., 2 April 2010) to estimate G_0 and its standard error.

Use of radio transmitters/receivers to locate tortoises is a technique that is very different from the method used to detect tortoises on line transects. Therefore, in addition to stating whether any part of the tortoise is visible when located, since 2008 behavioral observers and transect walkers have categorized all “visible” tortoises and burrows (when tortoises are found in burrows) as low, medium, or high visibility based on the ability to see part of the tortoise or its burrow from any angle of approach. For the telemetry observers it is a matter of locating a tortoise (visible or not) after they have determined its general location aurally, whereas transect walkers are not searching with certainty of locating a tortoise – they rely only on visual cues and have no leading information when a tortoise is in the vicinity. We would therefore not be surprised if the distance sampling method results in detection of a higher proportion of “high” visibility and a lower proportion of “low” visibility tortoises/burrows than when tortoises are located using telemetry. If the odds be being detected differ not only by distance from the line but also a combination of method of detection used (visual or radio receiver) and visibility, we should be able to describe this difference and be able to modify our calculation of visibility following radio-receiver information to more accurately match the visibility to transect walkers.

Field observer training

Training for careful data collection and consistency between crews is a fundamental part of quality assurance for this project. This training includes instruction as well as required practice time on skills such as tortoise handling, walking practice transects, and developing detection and distance-measuring techniques (Table 1). The monitoring handbook developed in 2008 was comprehensive, and serves as a training manual and documentation of training that is provided. Chapters posted to the Desert Tortoise Recovery Office website and printed for training have been updated each year as needed (http://www.fws.gov/nevada/desert_tortoise/reports).

In 2010, three teams of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in the West Mojave and Eastern Colorado recovery units. The Institute for Wildlife Studies (IWS) participated for the first time, monitoring in the Northern Colorado and Eastern Mojave recovery units. Great Basin Institute (GBI) supplied crews for monitoring in the Northeastern Mojave. About half the personnel for Kiva were trained for the first time in 2008 and returned each year. One of the 15 personnel for IWS had previous experience with this monitoring program, and 9 of the 30 personnel for GBI were returnees. Due to the large number of trainees, and to accommodate an earlier monitoring window on CMAGR, the three teams were trained in 2 overlapping periods, with some experienced Kiva personnel leaving the training group after rapid evaluation (Table 1). Where possible the same trainers were used in both training sessions and across teams. Also, for small-group training, experienced personnel from each team worked with the trainees from other teams.

Telemetry training

The primary goal of G_0 training is successful implementation of the G_0 protocol by telemetry crews. This includes correct use of telemetry equipment, understanding G_0 data collection fields, observation of as many radio-equipped tortoises as possible during the day, and covering a window of observation that overlaps the day's transect time window for each sampling area. Although all telemetry crews had some prior telemetry experience, performance on this project differs from others that do not require confirmation of the exact location of the tortoise. Unless the exact location is determined, its visibility cannot be accurately recorded. Beyond instruction and testing on use of the equipment in desert terrain, several days of practice were compulsory to be able to troubleshoot locating the tortoise and confirming the location when it could not be seen, In addition, some instruction for telemetry and transect crews overlapped to help each group better understand the purpose their data serve and how they fit with data that were collected under the other protocol.

Distance sampling training

Transect walkers were given classroom instruction, field demonstrations, practice transects to complete, and ultimately each team was evaluated based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001).

Table 1. Training schedule for 2010.

	IWS Trainees		**GBI Trainees**		**Kiva Trainees**	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 0			G0 only			
Thurs, 11-Mar	Beginning on-site G_0 instruction	Sparks	Beginning on-site G_0 instruction	Sparks		
Fri, 12-Mar	Familiarize G_0 with River Mtns	Sparks	Familiarize G_0 with River Mtns	Sparks		
WEEK 1			**WEEK 1**			
Monday, 15-Mar	Transect methods overview 6km transect	Allison/ Return crews			Transect methods overview 6km transect	Allison/ Return crews
Tuesday, 16-Mar	Introductions and DT Recovery/Monitoring Programmatic Overview	Allison			Introductions and DT Recovery/Monitoring Programmatic Overview	Allison
	Working on Public Lands	“			Working on Public Lands	“
	Tortoise Activity/G_0	“			Tortoise Activity/G_0	“
	Distance Sampling	“			Distance Sampling	“
	Transect methods lecture	“			Transect methods lecture	“
	Non-standard transects	“			Non-standard transects	“
	RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil			RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil
	Quality control procedures for field crews	Patil			Quality control procedures for field crews	Patil
	Compass/GPS Lecture	Allison	G0 on scheduled visit	Sparks	Compass/GPS Lecture	Allison
Wednesday, 17-Mar	Tortoise biology and handling instruction	Staff, Christopher	RDA/BT GPS, Pendragon Database Lecture and Exercises	Patil	Tortoise biology and handling instruction	Staff, Christopher
	Tortoise handling and data collection - small groups	“	Quality control procedures for field crews (transect and G0)	“	Tortoise handling and data collection - small groups	“
	Pen search image exercise	“	G0 in River Mtns -AM	Sparks	Pen search image exercise	“
	Training line lecture & crew quality control procedures	Allison/ Brenneman			Training line lecture & crew quality control procedures	Allison/ Brenneman
	Compass/GPS Exercise	Allison			Compass/GPS Exercise	Allison
	Data transfer and QA/QC (QAQC specialists only)	Patil	Data transfer and QA/QC (QA/QC specialists only)	Patil		
Thursday, 18-Mar	Training Lines (practice, 8km) Begin data download Beginning on-site G_0 instruction	Allison, Young Sparks			Training Lines (practice, 8km) Begin data download	Allison, Young
Friday, 19-Mar	Training Lines (practice, 8km) G_0 on-site training	 Sparks			Training Lines (practice, 8km) Begin data download from RDAs	
	Initial QAQC (specialists only)	Brenneman	Initial QAQC (specialists only)	Brenneman		
Saturday, 20-Mar					Full transects (12km)	

	IWS Trainees		GBI Trainees		Kiva Trainees	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 2						
Monday, 22-Mar	Tortoise handling Training line debriefing,	Staff Allison	Transect methods overview 6km transect	Allison/ Experienced crews	Tortoise handling Training line debriefing,	Staff Allison
Tuesday, 23-Mar	Training Lines (evaluation, 8km)		Introductions and Recovery/Monitoring Program Overview Same as IWS on 16 Mar	Allison	Training Lines (evaluation, 8km)	
Wednesday, 24-Mar	Training Lines (evaluation, 8km)		Tortoise biology and handling instruction Same as IWS on 17 Mar	Staff, Christopher	Training Lines (evaluation, 8km)	
Thursday, 25-Mar	Full transects (12km) (1/2 crew) G_0/activity observation -1/2 crew	Sparks	Training Lines (practice, 8km) Begin data download	Allison, Young		
Friday, 26-Mar	Full transects (12km) (half crew) G_0 / activity observation (half crew)	Sparks	Training Lines (practice, 8km)			
WEEK 3						
Monday, 29-Mar	Tortoise handling Training line debriefing	Allison	Full transects (12km) (1/2 crew) G_0 / activity observation (1/2 crew)	Sparks		
Tuesday, 30-Mar	Full transects (non-standard) or repeat training lines as needed G_0 on-site practice	Sparks	Tortoise handling Training line debriefing	Staff Allison		
Wednesday 31-Mar	Repeat training lines as needed *Begin field data collection*		Training Lines (evaluation, 8km)			
Thursday, 1-Apr			Training Lines (evaluation, 8km)			
Friday, 2-Apr			Full transects (12km) (1/2 crew) G_0 / activity observation (1/2 crew)	Sparks		
WEEK 4						
Monday, 5-Apr	Deliver QA/QC'd data from practice transects to ftp site		Tortoise handling Training line debriefing			
Tuesday, 6-Apr			Full transects (non-standard) or repeat training lines as needed G_0 on-site practice			
Wednesday 7-Apr			Repeat training lines as needed *Begin field data collection*			
WEEK 5						
Monday 12-Apr			Deliver QA/QC'd data			

Polystyrene models of desert tortoises (“models”) are set out on the training course each year using placement instructions (vegetation or open placement, distance along training line, and distance perpendicular from training line). This course is used to determine whether 1) individual teams are able to detect all models on the transect centerline, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

Crews were sent on transects and training lines as paired, independent observers. That is, the follower was 25 m behind the leader, with the opportunity to detect models not found by the leader. If the leader detects 80% of all tortoises that are found, the assumption is that the follower detects 80% of the tortoises that are missed by the leader. If this assumption is true, in this example, the pair together will detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. Because the location of all models was known, data from training lines were also used to 1) assess the dual-observer assumption that all models were equally detectable (detections attributed to the follower occur at the same rate as original detection rate by leader), and 2) to estimate the detection rate using this technique for tortoises elsewhere in the Mojave Desert. These data on models were used to evaluate and correct crew performance before the field season, but were not used in any way to estimate densities of live tortoises once field surveys began.

Data management including quality assurance and quality control

Two sets of data tables are maintained through the field season, organizing data collected on transects and at the G_0 sites. Collection data forms, sheets, applications, and databases are designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper formats by the two survey organizations, then combined and processed in a series of phases to create final database products. Data quality assurance and quality control (data QA/QC, also known as verification and validation) is performed during the data collection, data integration, and data finalization phases. During the second, data integration phase, after combining data from separate groups, some attribute fields are added and all fields are formatted for final processing. The third phase, data finalization, involves consolidation, resolution of data inconsistencies, and generation of final spatial and non-spatial data products used for analysis. After data analysis and reporting are completed, electronic data are actively hosted for download from the internet through http://www.mojavedata.gov/deserttortoise_gov/recovery/data.php. Figure 3 describes the overall data flow.

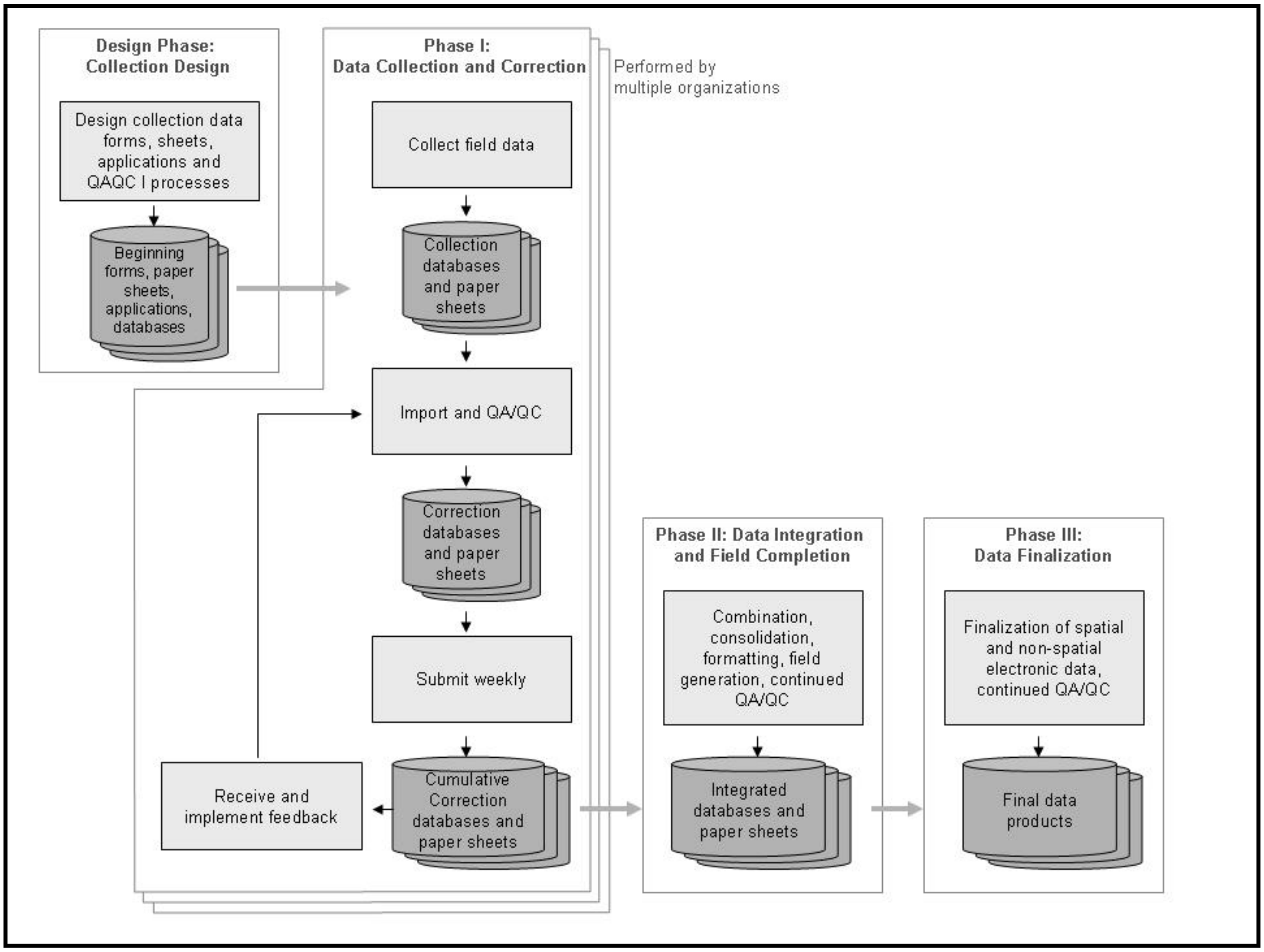

Figure 3. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a given distance from the transect centerline), and their respective variances. Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, and different detection protocols used by individual crews (pairs). Field teams (IWS, GBI, Kiva) typically walk a different proportion of the transects, so I expected to develop at least one curve for each field team, which also corresponds to different regions of the desert. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 6, Release 2 (Thomas et al., 2010) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. One record was created for each transect, with additional records for each additional tortoise on that transect. Analysis was applied to all live tortoises larger than 180 mm MCL. Transects were packaged into monitoring strata ("regions" in Program DISTANCE). I truncated observations to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001)**.** Using truncated data, I used the Akaike Information Criterion (AIC) to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended in Buckland et al. (2001).

Proportion of available tortoises detected on the transect centerline, *g(0)*

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were walked in a square, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25 m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows estimation of the proportion of tortoises detected on the line; this provides a test of the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $g = 1 – q^2$, where $q = 1 – p$. Figure 4 graphs the relationship between the single-observer detection rate (p) and the corresponding dual-observer detection rate (*g(0); "gee at zero"*). The actual proportion detected can be estimated, but to avoid the necessity of compensating for imperfect detection, during training field crews (pairs) are expected to detect 96% of all models within 1 m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near on the centerline in order to meet this standard (Fig. 4) and is the basis for one of the training metrics (see Table 3).

Few or no tortoises are located exactly on the line, and even examining a small interval (such as 1 m on each side of the transect line) results in few observations to precisely estimate *g(0)*. Instead, my test of the assumption involves examination of the lead and follow proportions starting with counts of tortoises in larger intervals from the line, moving to smaller intervals centered on the transect centerline. As the intervals get smaller the sample sizes also get smaller, but the estimates are more relevant to the area right at the transect centerline. The expectation is that the estimates should converge on $g(0) = 1.0$.

If the test does not indicate that all tortoises were seen on the transect centerline, the variance of p can be estimated as the binomial variance = $q(1 + q)/np$ (White et al., 1982), where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of *g(0)* is estimated as twice the variance of p.

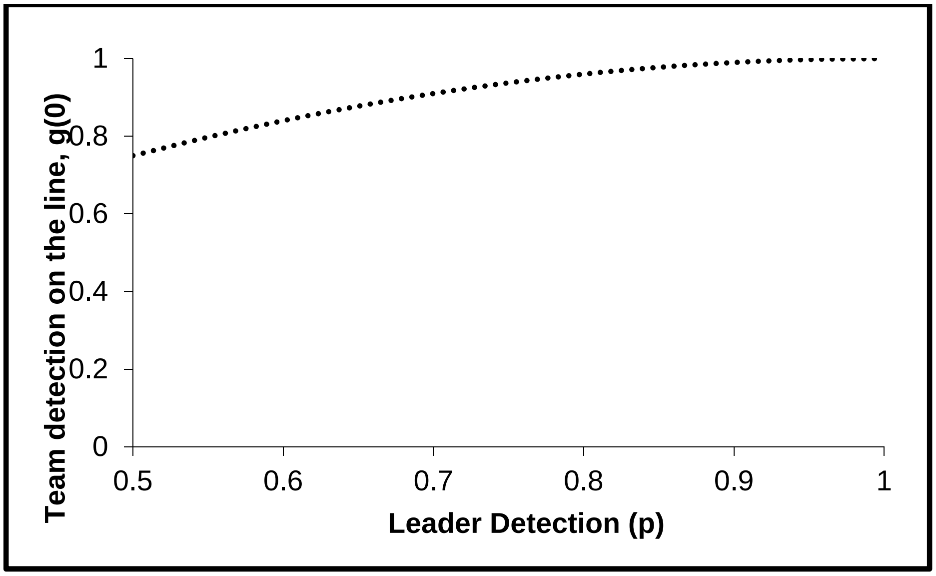

Figure 4. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the recovery unit. The calculation of these densities starts with estimates of the density of tortoises in each stratum from Program DISTANCE, as well as their variance estimates:

$$D = \frac{n}{2wLP_a G_0 g(0)},$$

where L is the total length of kilometers walked in each stratum and w is the distance to which observations are truncated, so $2wL$ is the area searched in each stratum. This is a known quantity (not estimated). P_a is the proportion of desert tortoises detected within w meters of the transect centerline and was estimated using detection curves in Program DISTANCE. The encounter rate (n/L) and its variance were estimated in Program DISTANCE for each stratum. Calculation of D requires estimation of n/L, P_a, G_0, and $g(0)$. This means that the variance of D depends on the variance of these quantities as well.

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum, whereas proportion of available tortoises and proportion of available tortoises detected on the transect centerline are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly or separately, depending on the number and quality of observations. In 2010, separate detection curves were created for GBI and IWS, pooled across all strata surveyed by each team. Although a single detection curve was also considered for Kiva detections, the patterns were very different in the south (mostly Colorado Desert) compared to the north (Mojave Desert), so separate curves were developed for strata in the two areas (see *Results*). A schematic of the process leading to density estimates is given in Figure 5. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates. Because transect records were associated with recovery units under the USFWS (1994) recovery plan, those recovery units are used here, although the data for 2010 and earlier years will be repackaged to later describe trends in the USFWS (2011) recovery units.

Whereas the number of tortoises in the set of strata representing a recovery unit can simply be added together, the variance must be arrived at by accounting for whether this involves pooled or independent estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data "pooled" from other strata as well, so when data from these strata are combined, the correlated nature of the variances has to be accounted for. Specifically, the method described in Buckland et al. (2001:89) was used to combine density variances correctly and arrive at the variance (and confidence intervals and CV) for the recovery unit. Variance estimates cannot currently be combined within Program DISTANCE as required for the analysis described here, so final construction of density mean and variance estimates from the above components was completed without specialized software.

<table>
<tr><th>Tortoise encounter rate</th><th>Proportion that are visible, G_0</th><th>Detection rate, P_a</th><th>Proportion seen on the line, $g(0)$</th><th>Density</th><th>Density</th></tr>
<tr><td>Stratum or</td><td>Neighboring G_0 sites</td><td>Data collection group</td><td>Overall</td><td>Stratum</td><td>Recovery unit</td></tr>
<tr><td>FK</td><td rowspan="3">Ord-Rodman + Superior-Cronese</td><td rowspan="3">Kiva north</td><td rowspan="15">Full set of tortoise observations</td><td>FK</td><td rowspan="5">Western Mojave</td></tr>
<tr><td>SC</td><td>SC</td></tr>
<tr><td>OR</td><td>OR</td></tr>
<tr><td>JT</td><td rowspan="4">Joshua Tree NP + Chuckwalla</td><td rowspan="4">Kiva south</td><td>JT</td></tr>
<tr><td>PT</td><td>PT</td></tr>
<tr><td>CK</td><td>CK</td><td rowspan="2">Eastern Colorado</td></tr>
<tr><td>AG</td><td>AG</td></tr>
<tr><td>CM</td><td rowspan="4">Piute + Chemehuevi + Ivanpah</td><td rowspan="4">IWS</td><td>CM</td><td>Northern Colorado</td></tr>
<tr><td>FE</td><td>FE</td><td rowspan="3">Eastern Mojave</td></tr>
<tr><td>IV</td><td>IV</td></tr>
<tr><td>PI</td><td>PI</td></tr>
<tr><td>GB</td><td>Gold Butte + Halfway Wash to 22 April</td><td rowspan="4">GBI</td><td>GB</td><td rowspan="4">Northeastern Mojave</td></tr>
<tr><td>BD</td><td rowspan="2">Halfway Wash after 22 April</td><td>BD</td></tr>
<tr><td>MM</td><td>MM</td></tr>
<tr><td>CS</td><td>Coyote Springs</td><td>CS</td></tr>
</table>

Figure 5. Process for developing density estimates in 2010. For each type of estimate, the full set of data was subdivided appropriately. USFWS (1994) recovery units are used for this analysis.

Estimating the area of each stratum sampled and the number of tortoises in that area
Before the 2008 field season, based on experience in 2007 and visual examination of DEM overlays, all assigned transects were classified as possible for completion as 12k, 6k, or as unwalkable (USFWS 2012). These classifications before the field season are advisory only, because exact ground conditions, weather, and crew condition all affect the ability to complete a transect. If a non-standard transect (not 12 km square) is walked, crews indicate the obstacles they encountered that forced the change in protocol. In addition to the above named factors, substrate that is very loose on a steep slope or that includes large boulders can make progress so slow or treacherous that crews modify the transect.

Each year, some transects are repeated, providing new information on ground conditions, and new transects are attempted. At the end of each field season, transects that were completed differently from expected are evaluated. At that point, a decision is made whether to reclassify the transect. The classification is used to advise future transect completion, but also to estimate the proportion of each monitoring stratum that is actually represented by the walked transects.

Because each transect of any length is built off of the southwestern corner, how that transect is completed is one representation of transects built on all possible southwestern corners. In order to avoid selection bias by crews, there were only 3 classification options for entire transects, so that only 0-, 6-, or 12-km were actually walked, but of course all of the distances between these options might actually have been walkable. Transects that were not walked represent all transects that could be walked for lengths of 0- to 6-km. It is parsimonious to therefore assume that on average, 3 km could have been walked for each transect classified as “unwalkable.” Transects completed using the 6km option represent all of those that could have been completed for distances of 6- to 12-km, averaging 9 km, so that is the expected value for all of those transects. Transects completed as 12 km represent the 100% completion option. The total area of the stratum that is unwalkable is estimated as:

$$Proportion\ unwalkable = \frac{0.25(\#\ 6k\ transects) + 0.75(\#\ unwalkable\ transects)}{\#\ transects\ classified\ since\ 2008}.$$

If a given stratum covers 5000 km^2, but only 90% was walkable and represented by our sampling design, then the density estimates applies to 4500 km^2, and can be used to generate an estimate for the number of tortoises in those 4500 km^2. Using these area estimates adds another source of imprecision, so abundance estimates are slightly less precise than the density estimates they derive from. The additional error of this estimate is calculated as the error for a binomial proportion.

Modification of previous procedures
In 2010, two new procedures for walking transects affect how we use transect completion information to estimate the proportion of each stratum that is walkable. First, in acknowledgment that public lands outside tortoise conservation areas increasingly used for activities that are not compatible with tortoise conservation, transects are now reflected inward from the [usually] invisible stratum boundaries. This new procedure has also caused the reclassification of some transects to walkable, where stratum boundaries exclude mountain ranges, for instance. Next, crews completed all transects except those walked by GBI in Nevada using the 12 km square path, completing as much of that path as possible. The calculation of unwalkable area in these strata now based on the proportion of unwalkable kilometers, not unwalkable transects.

Debriefing to describe strengths and weaknesses of project preparation and execution
At the end of each field season, a debriefing meeting was held to review tasks and responsibilities, strengths and weaknesses of the program, and to plan for the next field season. Because the field teams had disbanded by then, field crew members were surveyed prior to the end of the field season to nonetheless gather their direct input as we identified training and logistical issues to target for improvement before the next field season. Although issues and/or tasks may be ascribed to individual entities, this meeting is most beneficial in identifying where centralized and/or coordinated response is required to improve the quality of the program.

RESULTS

Field observer training
The smaller Kiva and IWS groups trained alongside one another and mostly separate from GBI, although experienced crews worked between all three teams. Training started on 11 March and continued through 6 April in 2 staggered sessions (Table 1). Final tests of field detection abilities occurred toward the end of this period.

Proportion of tortoises detected at distances from the transect centerline
Table 2 reports the proportion of models that were available and were detected by each team at 1-, 2-, and 5-meters from the transect centerline. Teams were tested after a trial run on the detection lines (GBI and IWS crews) or after walking practice transects for returning crews that wanted to refresh the search pattern (Kiva). Detection on the centerline should be 100%, and many crews achieved this. First-year trainees detected a similar proportion of models at 1- and 2-m compared to experienced crews, with first-year trainees detecting fewer models at 5 m.

Table 3 reports further statistics for each team after collecting data on 16 km on the evaluation lines. Column 4 reports the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. In contrast, on training lines, error in measurements is increased if crews do not walk on exactly the measured line that was used to place the models. On average, the measured distance of models to the centerline was 21 cm closer than the actual distance, with increasing bias for models farther from the line. The "Available Models Detected by Leader" column reports the proportion of all models that were found first by the leader. During training, this number is easily calculated and is used to identify crews in which one of the observers is not finding at least 80% of all detected. With an 80% detection rate for the leader, a 96% detection rate is expected for the team.

Table 2. Proportion of tortoise models detected within 1-, 2-, or 5-m of the transect centerline. Values that scored below the target of 0.90 at 1- or 2-m are highlighted.

	Proportion of existing models within a given distance detected by the team		
Team	1m	2m	5m
1	0.93	0.96	0.87
2	1.00	0.96	0.91
3	0.92	0.96	0.94
4	1.00	0.88	0.87
5	1.00	0.93	0.95
6	1.00	0.92	0.88
7	0.85	0.90	0.86
8	1.00	1.00	0.90
21	1.00	0.89	0.93
22	0.93	0.89	0.88
23	1.00	1.00	0.97
24	0.85	0.89	0.88
26	1.00	1.00	0.97
27	0.88	0.93	0.94
28	1.00	1.00	0.94
51	1.00	0.96	0.95
52	1.00	1.00	0.94
53	1.00	0.96	0.93
54	1.00	1.00	0.90
55	0.93	0.96	0.93
56	1.00	0.93	0.90
57	0.93	0.96	0.96
58	1.00	1.00	0.94
59	1.00	0.96	0.91
60	1.00	0.96	0.92
61	1.00	0.96	0.88
62	1.00	1.00	0.94
GBI	**0.99**	**0.97**	**0.93**
Kiva	**0.96**	**0.94**	**0.90**
IWS	**0.95**	**0.94**	**0.93**
Overall	**0.97**	**0.95**	**0.92**

Table 3. Diagnostics for individual teams after training.

Team	Available models detected: Within 2m of centerline by leader	Available models detected: Within 2m of centerline by team	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval: Lower limit	95% confidence interval: Upper limit
1	0.85	0.96	0.79	396	302.3	519.3
2	0.81	0.96	0.79	377	326.8	434.6
3	0.89	0.96	0.96	409	343.7	485.5
5	0.81	0.88	0.77	443	359.6	546.0
6	0.86	0.93	0.84	397	345.1	457.4
7	0.88	0.92	0.73	375	319.7	439.7
8	0.87	0.90	0.78	378	341.5	417.3
21	0.93	1.00	0.79	682	524.3	888.1
22	0.85	0.89	0.76	356	318.4	398.9
23	0.85	0.89	1.14	433	394.1	474.6
24	0.96	1.00	0.89	408	326.9	509.6
26	0.89	0.89	0.79	366	324.1	412.2
27	1.00	1.00	0.82	427	313.5	582.3
28	0.86	0.93	0.74	402	296.0	547.2
51	1.00	1.00	0.87	390	325.3	467.5
52	0.86	0.96	0.80	370	330.8	413.8
53	1.00	1.00	0.87	403	365.2	443.8
54	0.85	0.96	0.75	441	369.7	526.0
55	0.92	1.00	0.55	345	294.6	403.1
56	0.88	0.96	1.01	475	388.1	580.5
57	0.89	0.93	0.80	384	286.8	513.3
58	0.81	0.96	0.81	451	377.2	539.7
59	0.86	1.00	0.63	464	380.1	566.3
60	0.86	0.96	1.02	477	355.8	639.5
61	0.89	0.96	0.80	343	297.8	394.1
62	0.96	0.96	1.13	461	384.1	553.8
Target	**>0.80**	**>0.90**	**<1**	**410**		
GBI	**0.91**	**0.97**	**0.83**	**415.2**		
IWS	**0.97**	**0.94**	**0.86**	**397.4**		
Kiva	**0.92**	**0.94**	**0.81**	**432.1**		
Overall	**0.93**	**0.95**	**0.83**	**415.6**		

During training, personnel on 2 teams were switched after unsuccessful practice runs. The resulting 2 teams are included in Tables 2 and 3. Although some individual metrics were below-par (gray cells in the above tables), the teams were all judged to perform well overall and no further changes were made. During training, various detection curves were fit to each crew's set of tortoise model observations. In no case did a negative exponential model best describe the data. Because this model does not involve fitting a “shoulder” to the data near the centerline, these detection curves would have been unacceptable. The best-fitting of the 3 remaining basic types of models were then fit to the data to generate the density estimates in Table 3. In Figs. 6-8, each crew’s data were fit to uniform or half-normal models for illustration purposes. Crews were not evaluated on their ability to a particular curve shape; however, we did provide guidance to individual crews to better match the search patterns of their teammates. This was taken as an opportunity to focus field personnel on an additional level of conformity. Distance sampling and development of a single detection curve from many observers is robust to the effects of pooling across observations from crews with variable search patterns, as long as all of the observers contribute proportionally to the overall pattern (Marques et al., 2007).

Within the GBI crews, teams 51 and 52 had the most anomalous curves (broadest shoulders) in Figure 6. These teams were coached on tightening their search pattern to better match other teams; however, neither team had other diagnostic issues. Although the IWS trainee curves as a group had broader shoulders than the GBI curves, they were similar to one another, and no problems are evident. The Kiva detection curves were more disparate between themselves. Three of these teams (1, 3, and 8) left training a few days earlier than the others. They had passed all of the training metrics and left to match the earlier opening of CMAGR. Although the other teams received feedback and worked to match one another’s detection curves in the final trials, the first three teams (the ones with the narrowest shoulders that most rapidly lose detections with increasing distance from the line) did not.

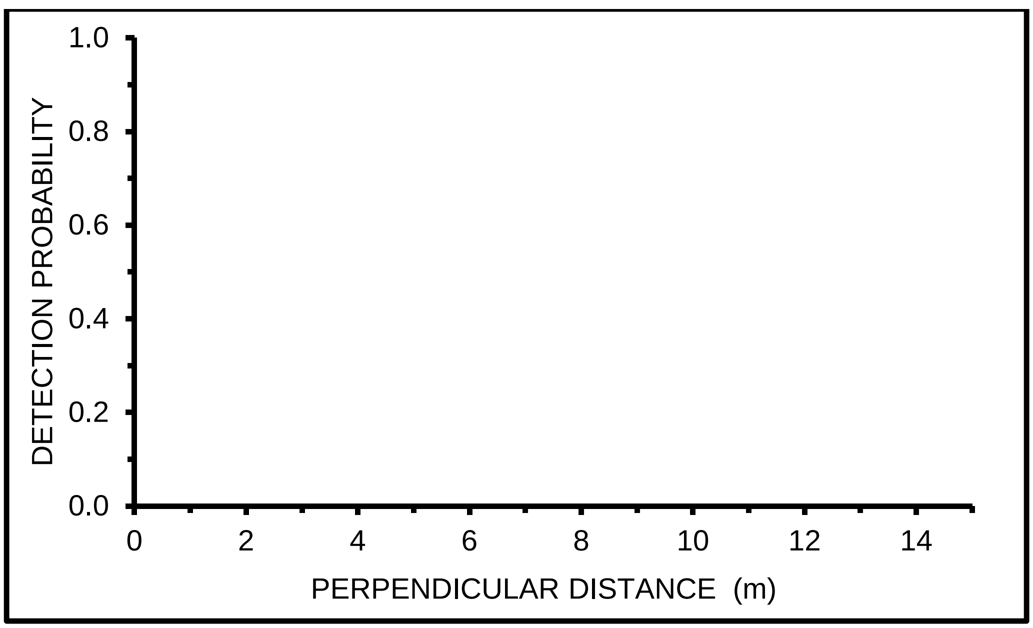

Figure 6. Detection curves for each of the 2010 GBI teams during training. Curves are based on 16 km trials with approximately 100 detections. Anomalous patterns described in text are indicated with dotted lines.

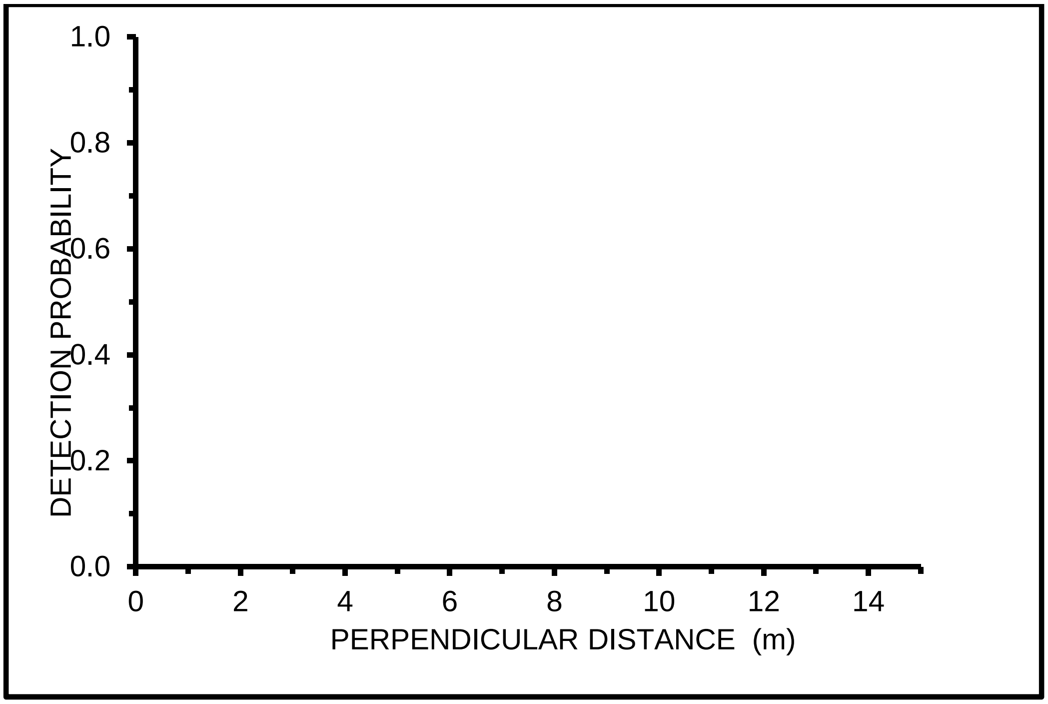

Figure 7. Detection curves for each of the 2010 IWS trainee teams. Curves are based on 16 km trials with approximately 100 detections.

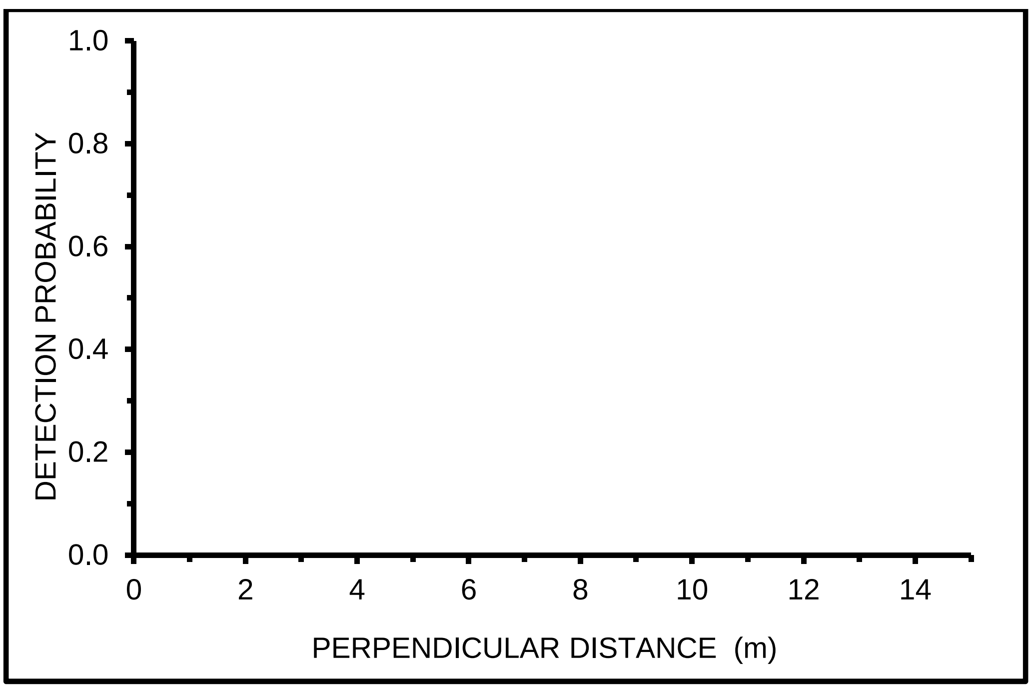

Figure 8. Detection curves for each of the 2010 Kiva trainee teams. Curves are based on 16 km trials with approximately 100 detections. Anomalous patterns described in text are indicated with dotted lines.

Quality assurance and quality control

There were 23,710 transect records and 5762 G_0 records associated with the monitoring effort in 2010. After data specialists with the field teams had finished verifying and validating the data, there were still 706 cases where data were inconsistent with constraints and expectations. (Many more issues are addressed by data specialists for field crews before the field data are submitted.) Of these, 681 were errors created by the field crews (sometimes faulty equipment, other times data entry error). Two hundred fifty of these could be corrected based on information collected on paper datasheets, while fields that should have been populated by faulty equipment could not be addressed. Another 22 errors were “processing” errors. Processing steps are associated with correcting other errors (perhaps a word is misspelled) or with adding new fields, or any other manipulation that occurs after the data have been collected. This year the bulk of the processing errors involved additional decimals in the elevation field.

Transect completion

Table 4 reports the number of assigned and completed transects in each stratum. Kiva was assigned 328 transects and walked this number, but were not always able to replace assigned unwalked transects with alternates in the same strata. As a result, too few transects were completed in Chuckwalla, Joshua Tree, and Pinto Mountain strata and all 7 of these transects were later completed in northern strata. All assigned transects were completed or replaced by IWS. One transect was inadvertently walked twice (counted once) and at the end of the field season one crew was able to complete an additional transect that was not a replacement for any assigned one. GBI completed more transects then the other 2 teams and also had more errors. Eight transects were walked on two separate occasions (duplicates are counted as one transect in Table 4). Three of the duplicated transects were purposely repeated when the first attempt was not completed to protocol or when illness interrupted the first attempt. For a variety of reasons, including logistical ones, 8 assigned transects were neither completed nor replaced by alternates in their strata, and 2 additional transects were completed in strata that did not need replacements.

Great Basin Institute began to address the issue of route-less areas that have not been accessible in any past years. Base-camping into these areas allowed crews to be provisioned with supplies, including water. This resulted in completion of 24 transects where crews would otherwise have had to hike 5 km or more one way to access transects. Any field personnel provisioning these base camps for other crews are not themselves walking transects.

Table 4 indicates the number of assigned transects that could be completed as standard square 12km transects (column 4), as well as the number that were completed by reflecting around obstacles. These transects are all considered to represent flatter topography in the monitoring stratum. An additional number (column 5) were completed as 6 km squares (GBI) or shortened as little as possible (IWS and Kiva), and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6).

The last 2 columns of Table 4 represent situations that were not anticipated. Crews were to shorten or abandon transects if the terrain presented too much of an obstacle, but reflecting around terrain was not a planned option. However, on some, relatively rare, occasions (column 7), crews had partially walked a transect before determining that it could not be completed following the correct protocol. In these situations, they would not have sufficient time to move to an alternate transect on the same day, so they instead reflected around terrain to collect data for the lower topography portion of the current transect.

Column 8 reports transects that appear walkable based on remote imagery but were not completed. All of these were reevaluated and some were reclassified based on this [additional] year of field information (see *Evaluating transect classification*, below). Note that transects on military installations (CMAGR, Ft. Irwin, China Lake, and Edwards AFB) are regularly but unpredictably inaccessible due to military activities. This corresponds to the 7 transects listed here for CMAGR (AG), 2 on Superior-Cronese, and 1 on Fremont-Kramer. Figures 9 through 12 show locations of transects and observations of live tortoises.

Table 4. Number and type of transects in each stratum. Stratum abbreviations as in Fig. 1.

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable	Assigned, completed by reflecting to avoid terrain	Assigned, judged walkable, but not walked*
AG	33	33	22	3	8		7
BD	68	66	38	22	6		1
CK	64	61	34	21	6		3
CM	40	40	30	2	8	1	2
CS	100	99	58	21	20		9
FE	20	20	18	2	0		
FK	50	50	41	7	2		2
GB	130	128	59	46	23	4	7
IV	30	31	23	3	4		1
JT	27	25	11	11	3		1
MM	132	132	65	52	13		7
OR	25	25	14	7	4		1
PI	44	44	30	8	6	3	2
PT	20	21	8	6	4		
SC	109	113	91	12	6		3
Total	892	888	542	223	113	8	46
GBI	430	425	220	141	62	4	24
IWS	134	135	101	15	18	4	5
Kiva	328	328	221	67	33	0	17

*Assigned transects that were not walked were supposed to be replaced by alternates.

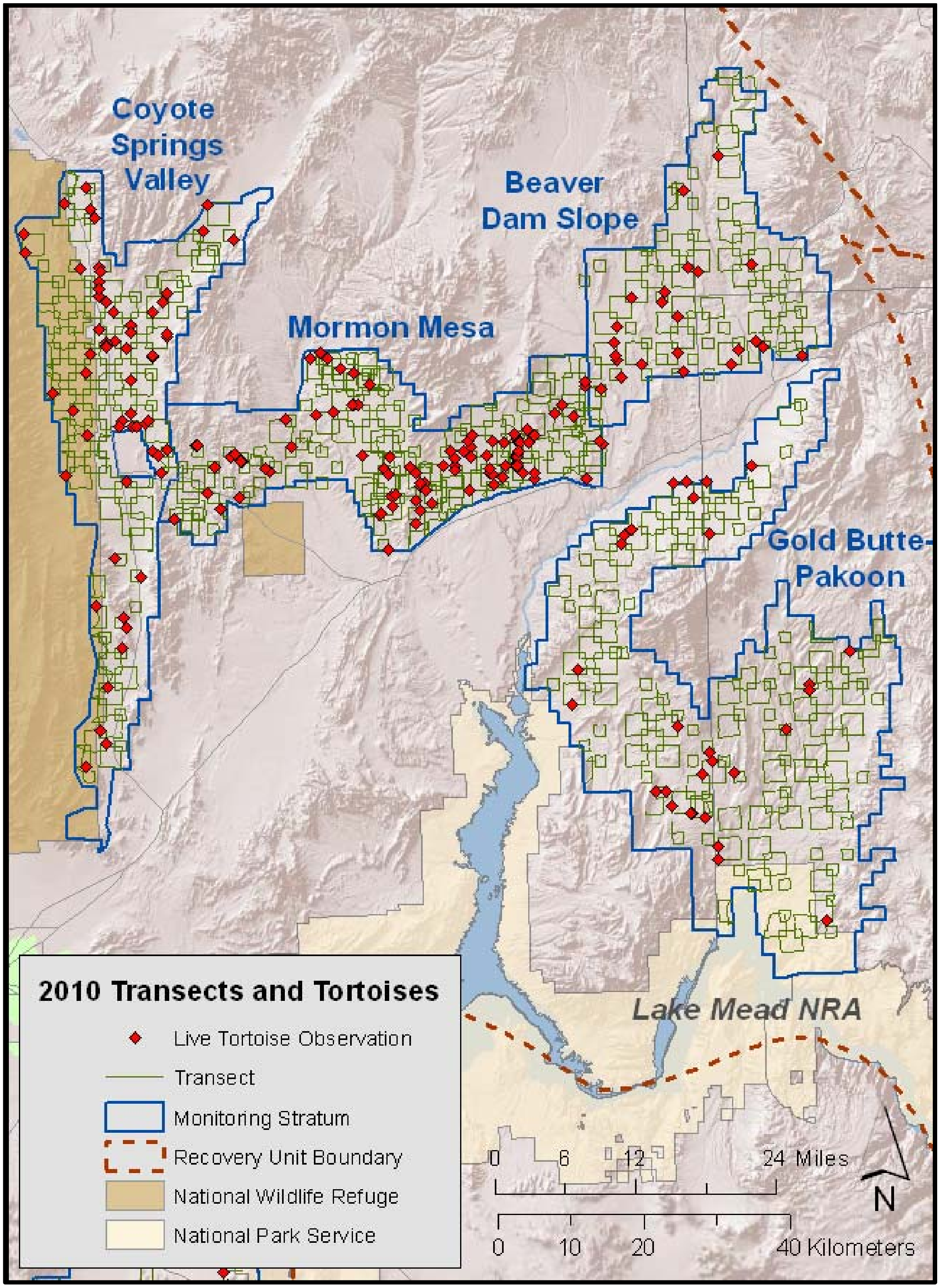

Figure 9. Distribution of distance sampling transects and live tortoise observations in the Northeastern Mojave Recovery Unit (Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata).

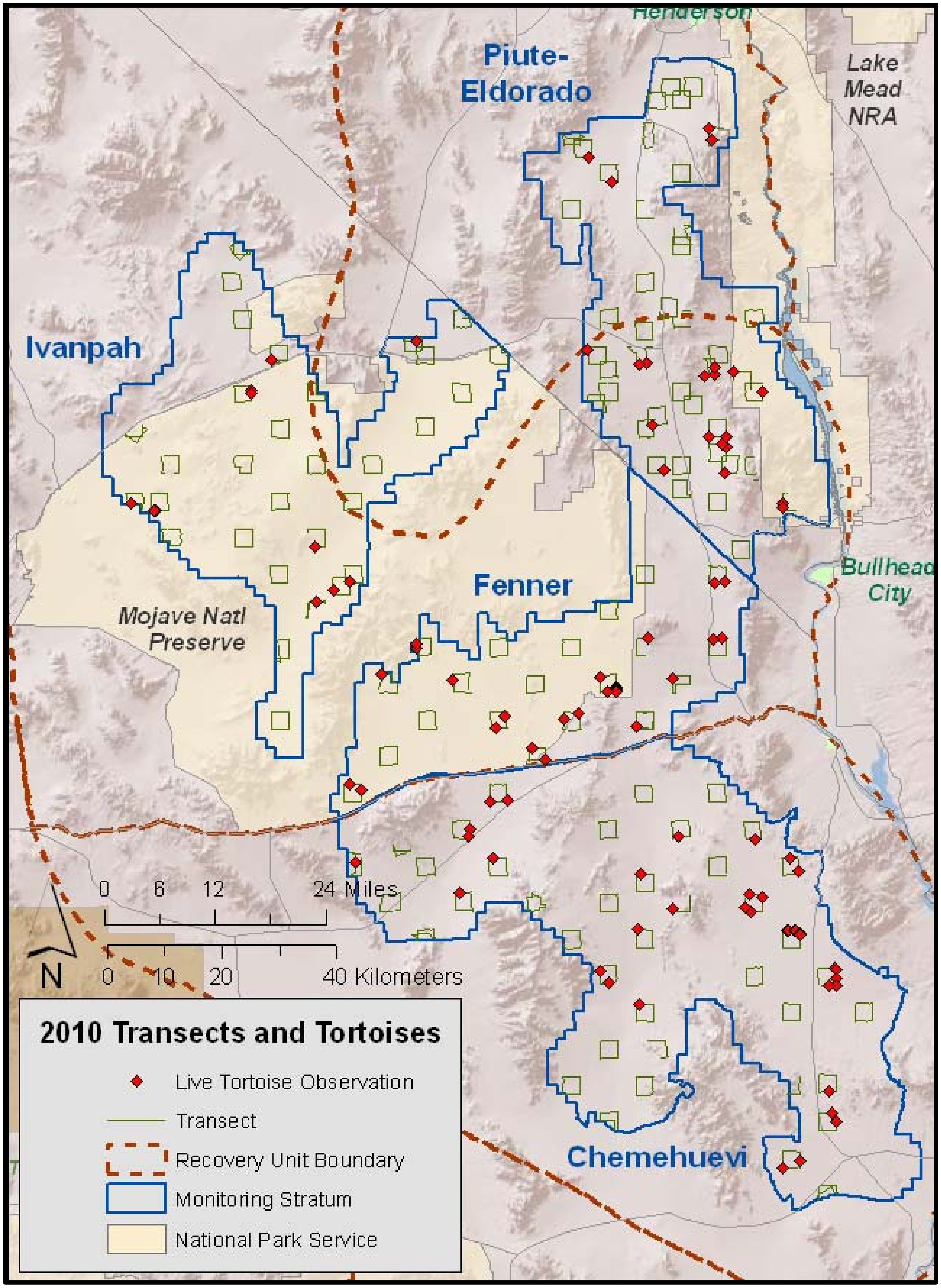

Figure 10. Distribution of distance sampling transects and live tortoise observations in the Eastern Mojave Recovery Unit (Piute-Eldorado, Ivanpah, and Fenner monitoring strata), and the Northern Colorado Recovery Unit (Chemehuevi monitoring stratum).

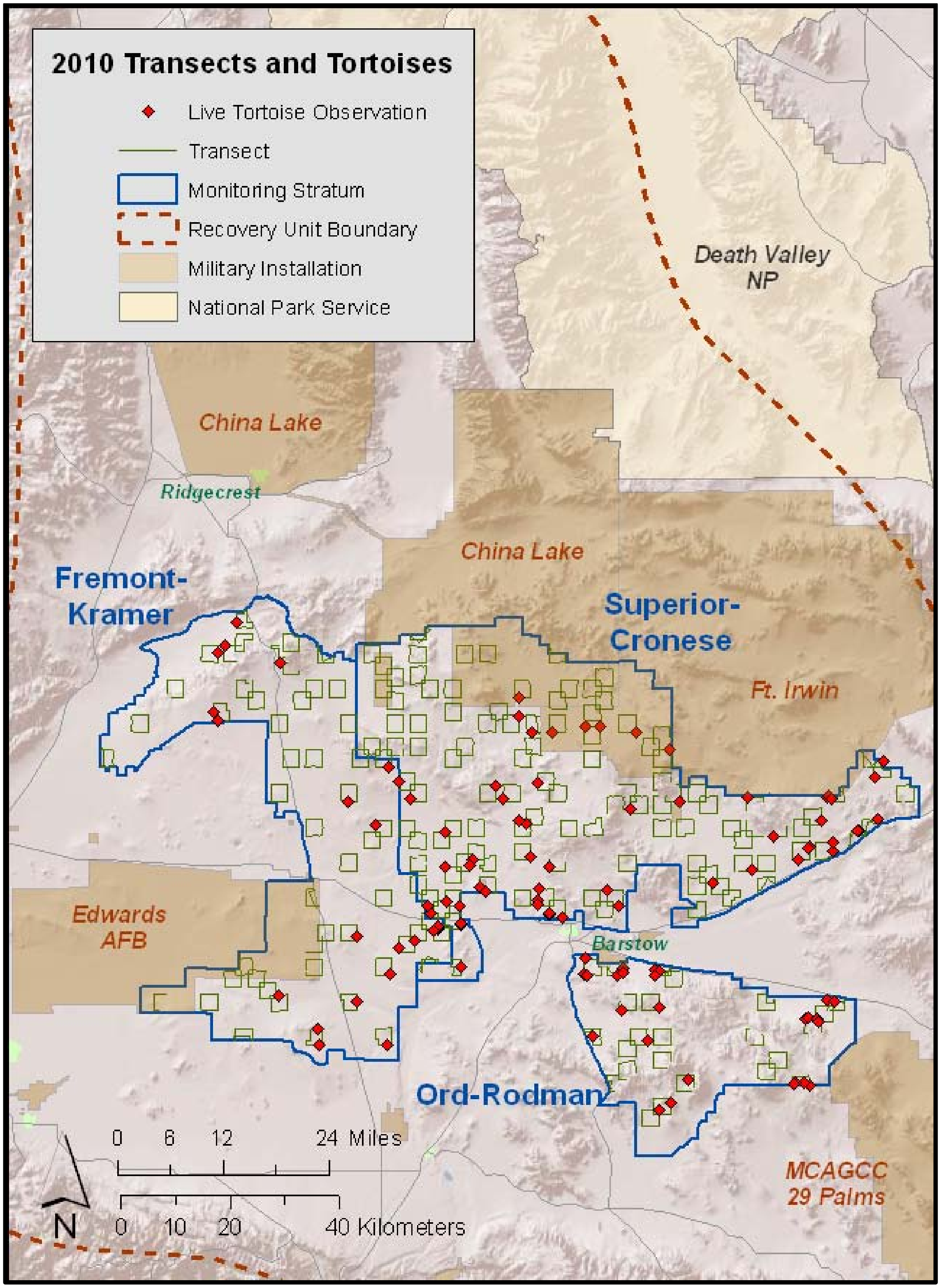

Figure 11. Distribution of distance sampling transects and live tortoise observations in the northern portion of the Western Mojave Recovery Unit (Fremont-Kramer, Superior-Cronese, and Ord-Rodman monitoring strata).

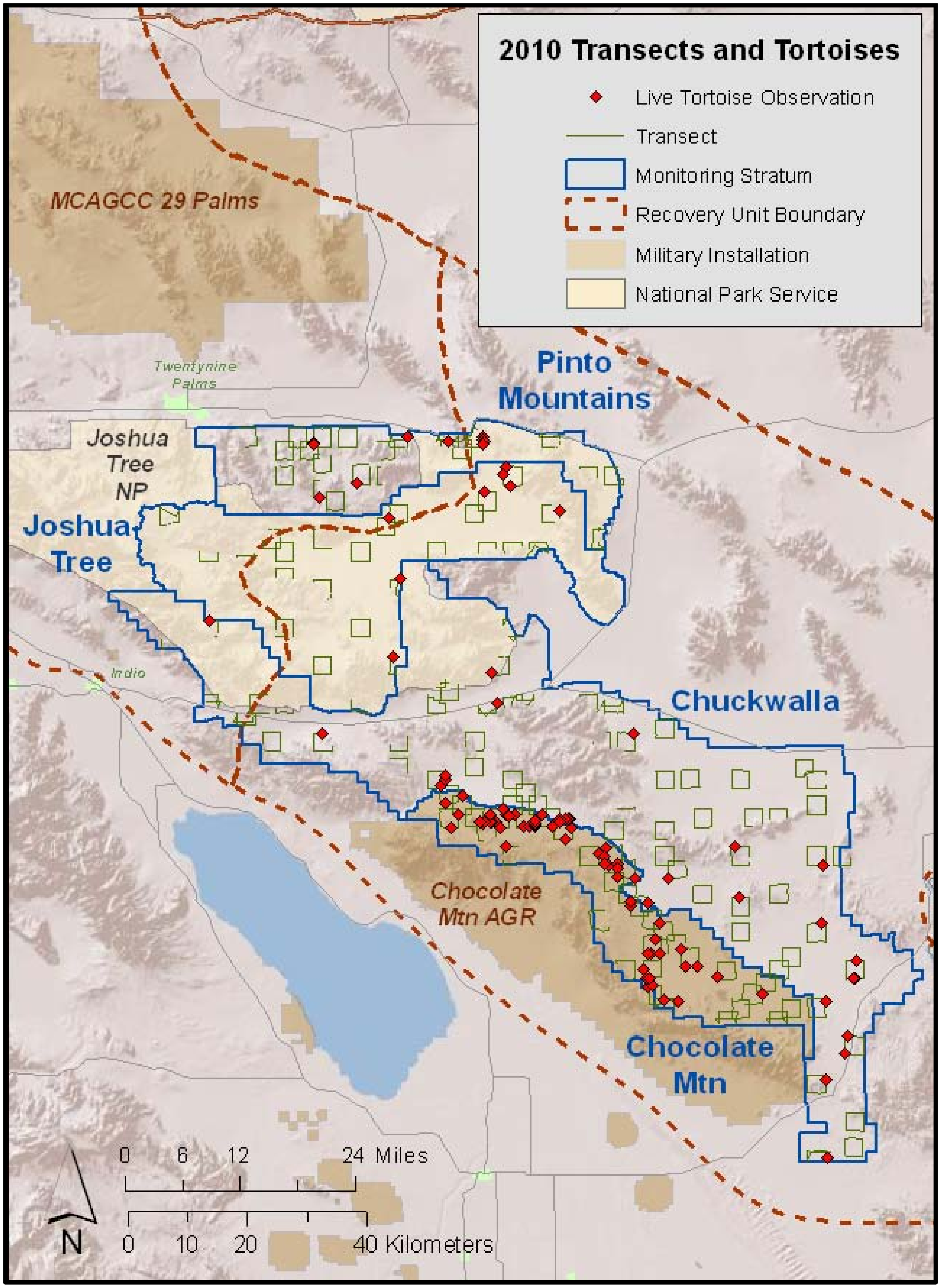

Figure 12. Distribution of distance sampling transects and live tortoise observations in the southern portion of the Western Mojave Recovery Unit (Pinto Mountains and Joshua Tree monitoring strata) and the Eastern Colorado Recovery Unit (Chuckwalla and Chocolate Mountain monitoring strata).

Tortoise encounter rates and detection functions

In 2010, all pairs worked together from the beginning to the end of the season. Each Kiva crew walked a median of 41 transects and overall they detected 196 tortoises over 180 mm MCL; GBI crews walked a median of 35 transects and detected 179 tortoises; and IWS crews had considerably lower effort, with a median of 23 transects (days of work). However, each IWS observer subsequently walked 1-person distance transects in a separate study at the Large Scale Translocation Site near Jean, Nevada; altogether IWS personnel completed 40 days of work and the team observed 122 tortoises, and the LSTS encounters were used to model the overall IWS detection probability illustrated in Fig. 14. There were sufficient observations to generate separate detection curves for each team, so I planned a minimum of 3 detection curves.

Figures 13 to 16 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. There is one histogram each for IWS and GBI, plus separate histograms for Kiva detections in the northern and southern areas that they surveyed. These observations were used to model detection curves, overlaid in the same figures. Based on detection function behavior, it is typical to discard a few observations in the tails of the histograms in order to build a more robust model (Buckland et al. 2001). Each figure indicates the customized truncation distance that was applied. Any observations that are not used to estimate detection functions will also not be used to estimate the encounter rate (tortoises detected per kilometer walked). Tortoise encounter rates are low enough that this becomes a factor in considering how to truncate observations to develop detection functions. Truncation was conservative in order to maximize the number of observations per stratum.

For GBI, the best half-normal and uniform models were within ΔAIC=1.47 of the better-fitting hazard rate model, with much better precision for the half-normal model but no meaningful difference in density estimate between the half-normal and hazard rate models. On the basis of precision, I used the half-normal model with second-order cosine adjustment to fit the detection function. The second-order adjustment is seen in the extra inflections in the tail of the curve (Fig. 13). This additional data fitting was called for unless observations were truncated at 8 m, with an unacceptable loss of 38 additional observations. For IWS, data were truncated at 14 m and fit best to a uniform model with a single cosine adjustment. I evaluated separate curves for northern and southern detections by Kiva because there were sufficient detections for two curves and because these transects represent a long north-south gradient, The AIC for the single model was greater than the sum of AICs for the separate models with the same truncation distance (same data), so separate models better fit the data. In the north (Fremont-Kramer, Ord-Rodman, and Superior-Cronese), the data were truncated at 12 m and fitted best to a uniform model with cosine adjustment. In the south, data were truncated at 8 m and fit to a half-normal model.

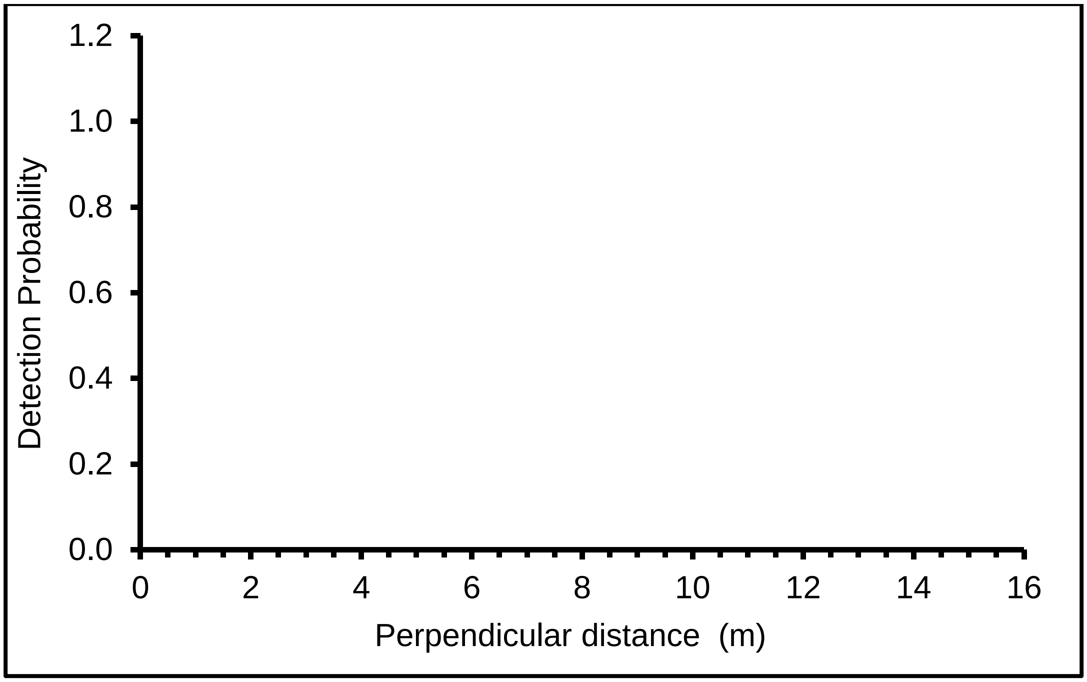

Figure 13. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. This curve uses only the 164 tortoise seen within 16 m of the centerline.

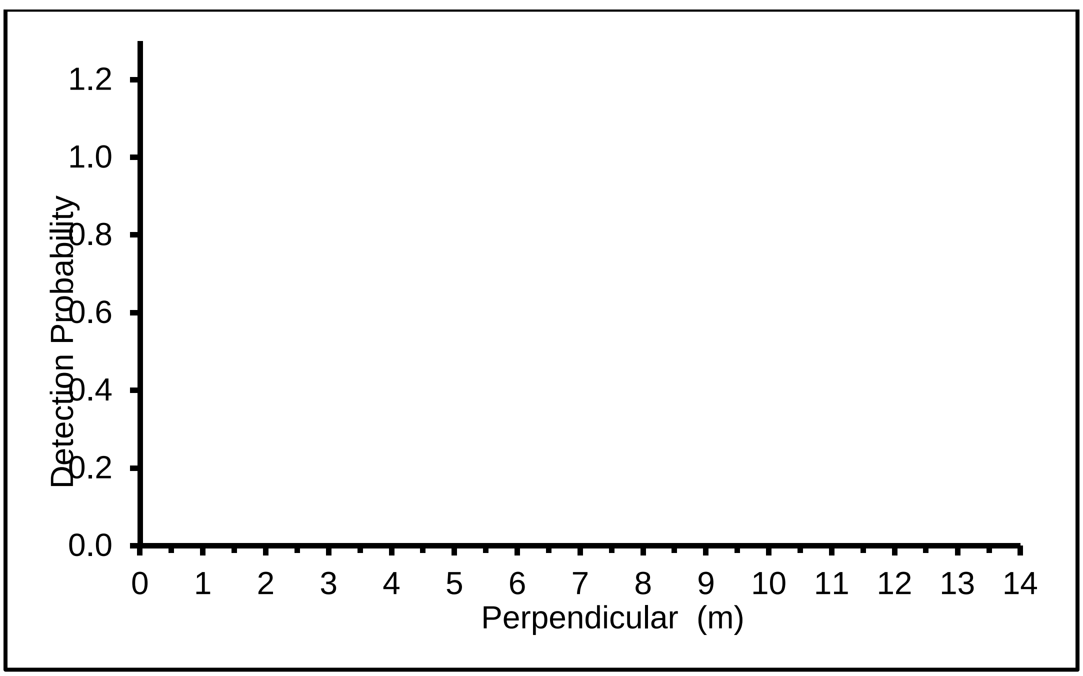

Figure 14. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by IWS. This curve uses only the 111 tortoises seen within 14 m of the centerline.

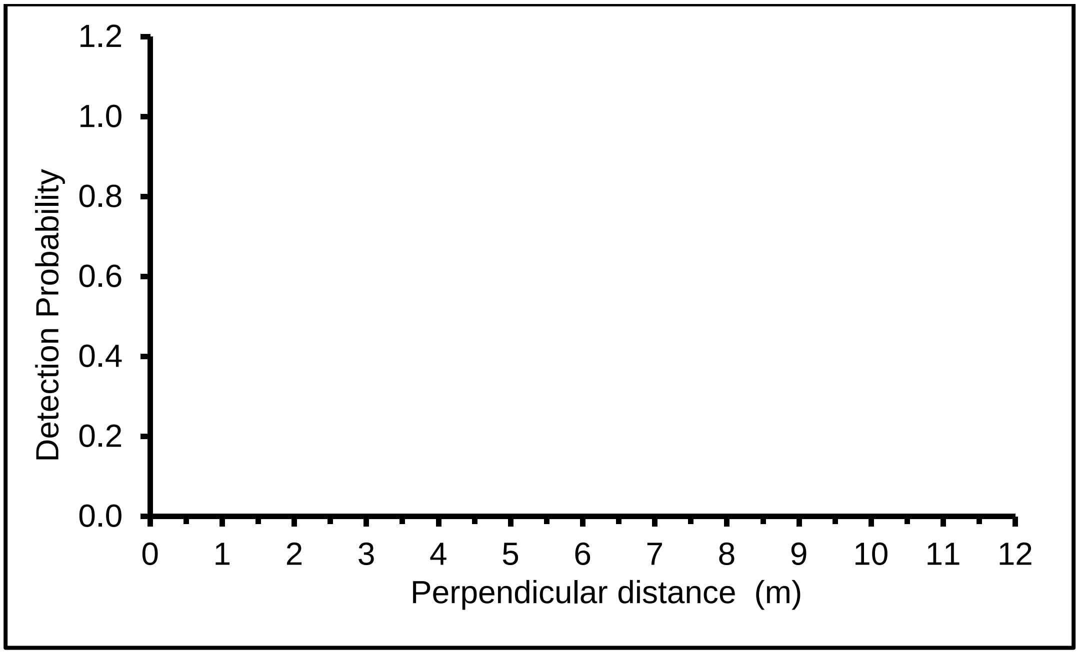

Figure 15. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL $\geq$ 180mm found by Kiva in Fremont-Kramer, Superior-Cronese, and Ord-Rodman. This curve uses only the 92 tortoises seen within 12 m of the centerline.

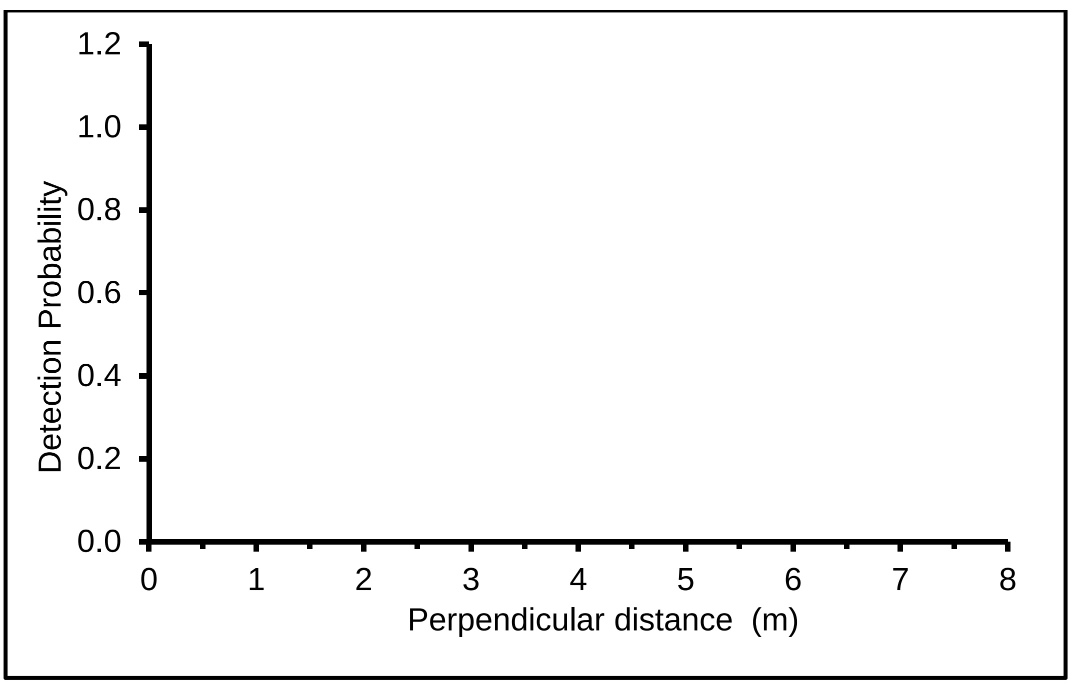

Figure 16. Observed detections (histogram) and fitted detection function (smooth curve) for live tortoises with MCL $\geq$ 180mm found by Kiva in Joshua Tree, Pinto Mountains, Chuckwalla, and on CMAGR. This curve uses only the 85 tortoises seen within 8 m of the centerline.

The area below each of the curves in Figs. 13–16 is the proportion of tortoises that were detected, P_a, estimated as far as the truncation distance (the farthest distance on the x-axis in each figure). Based on these curves, GBI detected 41.2% of the visible tortoises within 16 m of the centerline (CV=0.085). The corresponding estimate of P_a for strata surveyed by IWS was 58.6% (CV=0.060) within 14 m, for Kiva in the north was 58.3% (CV=0.070) within 12 m, and for Kiva in the south it was 67.1% (CV=0.100) within 8 m.

Proportion of tortoises available for detection by line distance sampling, G_0

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; peaking first in the south. Tortoise availability was estimated separately transects in each of these areas. Dates, total days monitored, and G_0 estimates are given in Table 5.

Table 5. Availability of tortoises (G_0) during the period in 2010 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Gold-Butte/ Halfway Wash	Gold Butte	7 Apr – 22 Apr	16	0.77 (0.177)
Halfway Wash	Beaver Dam Slope, Mormon Mesa	23 Apr – 15 May	23	0.80 (0.115)
Coyote Springs Valley	Coyote Springs	16 May – 28 May	13	0.86 (0.130)
Piute/ Ivanpah/ Chemehuevi	Piute-Eldorado, Chemehuevi, Fenner, Ivanpah	31 Mar – 29 Apr	30	0.82 (0.179)
Joshua Tree/ Chuckwalla	Chocolate Mtns, Chuckwalla, Joshua Tree, Pinto Mtns	23 Mar – 10 Apr	19	0.89 (0.122)
Ord-Rodman/ Superior-Cronese	Fremont-Kramer, Ord-Rodman, Superior-Cronese	13 Apr – 6 May	24	0.96 (0.066)

Proportion of available tortoises detected on the transect centerline, *g(0)*

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. For 50 detections of tortoises within 1 m of the transect centerline, 44 were found by the observer in the lead position and 6 by the follower, so that the probability of detection by single observer, p = 0.864, and the proportion detected using the dual observer method, *g(0 to 1 m)* = 0.981 (SE = 0.06). Figure 17 shows that *g(0)* was converging on 1.0, indicating the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate. The curves since 2004 all support the premise that complete detection on the transect line was achieved for years in which the dual-observer method was used (USFWS 2009, 2012).

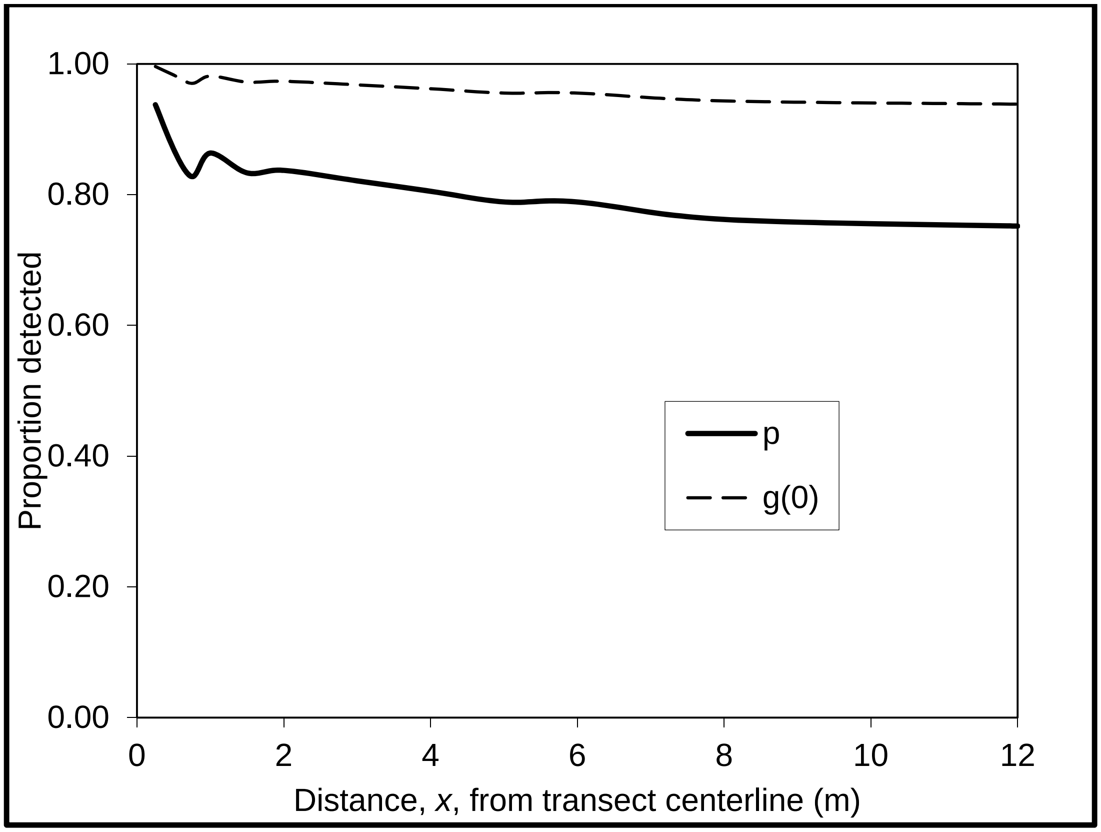

Figure 17. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2010. Note convergence of *g(0)* on 1.0 at the transect centerline as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 6), then weighted by stratum area to arrive at average density in the monitored area of each recovery unit (Table 7). Although encounter rates were estimated separately for each stratum, and have independent variances, the detection function and G_0 were estimated jointly, pooling data from multiple strata, so these variances are not independent (Fig. 5 illustrates how estimates were pooled for 2010).

When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this “background noise.” The CVs in 2010 represent an overall improvement in precision from previous years, a function of improved funding in this one year.

Table 6. Recovery unit and stratum-level encounters and densities in 2010 for tortoises with MCL ≥ 180mm.

Recovery Unit	Stratum		Area (km^2)	Number of Transects	Total transect length (km)	Sampling Dates		Field Observers	n (tortoises observed)	CV(n)	Density ($/km^2$)	CV(Density)
						Begin	End					
Northeastern Mojave			**4889**	**425**	**4265**	**7-Apr**	**28-May**		**164**		**3.2**	**15.8**
	Beaver Dam Slope	BD	828	66	662	23-Apr	15-May	GBI	23	22. 8	3.3	28.2
	Coyote Springs Valley	CS	1117	99	1046	16-May	28-May	GBI	43	16.7	3.6	24.0
	Gold Butte-Pakoon	GB	1977	128	1258	7-Apr	22-Apr	GBI	22	25.0	1.7	35.1
	Mormon Mesa	MM	968	132	1298	24-Apr	16-May	GBI	76	12.3	5.5	20.7
Eastern Mojave			**6763**	**95**	**1096**	**31-Mar**	**29-Apr**		**46**		**3.3**	**29.6**
	Fenner	FE	1862	20	246	31-Mar	27-Apr	IWS	23	28.3	6.9	36.1
	Ivanpah	IV	2567	31	365	1-Apr	29-Apr	IWS	5	41.6	1.0	47.3
	Piute-Eldorado	PI	2334	44	485	31-Mar	29-Apr	IWS	18	24.6	2.7	33.3
Northern Colorado			**4038**	**40**	**458**	**31-Mar**	**30-Apr**		**26**	**24.7**	**4.2**	**33.4**
	Chemehuevi	CM	4038	40	458	31-Mar	30-Apr	IWS	26	24.7	4.2	33.4
Western Mojave			**9336**	**234**	**2591**	**23-Mar**	**6-May**		**105**		**3.1**	**14.8**
	Fremont-Kramer	FK	2462	50	574	15-Apr	6-May	Kiva	19	22.5	2.5	24.5
	Joshua Tree	JT	1567	25	227	25-Mar	13-Apr	Kiva	6	53.9	2.8	56.5
	Ord-Rodman	OR	1124	25	270	17-Apr	4-May	Kiva	27	22.8	7.5	24.8
	Pinto Mountains	PT	751	21	213	25-Mar	10-Apr	Kiva	7	51.4	3.4	54.2
	Superior-Cronese	SC	3447	113	1307	13-Apr	6-May	Kiva	46	15.9	2.6	18.7
Eastern Colorado			**4263**	**94**	**991**	**23-Mar**	**10-Apr**		**72**		**5.7**	**18.9**
	Chocolate Mountain	AG	755	33	378	25-Mar	5-Apr	Kiva	50	19.2	13.8	25.6
	Chuckwalla	CK	3509	61	613	23-Mar	10-Apr	Kiva	22	25.3	3.7	30.4

Table 7. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave and Colorado deserts in 2010.

Recovery Unit	Area (km^2)	Kilometers walked	Tortoises detected	Density ($/km^2$)	Lower limit 95% CI (Density)	Upper limit 95% CI (Density)	%CV (Density)
Northeastern Mojave	4889	4265	164	3.2	2.36	4.38	15.8
Eastern Mojave	6763	1096	46	3.3	1.86	5.79	29.6
Northern Colorado	4038	458	26	4.2	2.22	7.95	33.4
Western Mojave	9236	2591	105	3.1	2.36	4.20	14.8
Eastern Colorado	4263	991	72	5.7	3.97	8.28	18.9

Area of each stratum sampled and the number of tortoises in that area

Evaluating transect classification

In 2010, 196 of the 888 walked transects were not completed as predicted. The following table summarizes conclusions after examining these transects.

Table 8. Transects completed other than as planned and any resulting reclassification

Previous substratum	Situation	New substratum	Number of transects
12k	On-the-ground observation differs from imagery	6k	21
12k	Shortened in 2010, but previous experience or correct modification would allow completion	12k	52
6k	On-the-ground observation differs from imagery	12k	31
Unwalkable	On-the-ground observation differs from imagery	12k	16
Unwalkable	New rules to reflect into stratum moved transect out of too-rugged terrain	12k	12
Unwalkable	On-the-ground observation differs from imagery	6k	19
6k	Lengthened in 2010, but other crews might be unable to walk as a 12k	6k	18
Unwalkable	Crew completed the transect using incorrect protocols or attempted new rules but couldn't walk at least 6km	Unwalkable	11
Unwalkable	New shortening rules allowed at least 6km completed, but earlier rules would have classified these as unwalkable	Shortened	16

Twenty-eight transects that would have been unwalkable under the previous protocols were attempted and completed this year using new rules to reflect into stratum boundaries (range-wide) and to shorten transects by walking only the safely walkable portions of the 12 km route (Kiva and IWS field teams only). In the first case, 12 transects were completed because they were correctly reflected into strata under new rules. These otherwise unwalkable transects were completed because stratum boundaries were often drawn to exclude more rugged topography. Sixteen previously unwalkable transects were walked for at least 6 km using new rules to shorten transects without completing the SW quadrant. These would still be “unwalkable” under the original classification system.

After the field season, 168 anomalous transects were reviewed. Of these, 87 were reclassified based on crew experience. In some cases, the crews encountered substrate or other features that were not apparent from imagery; in many others, the original classification based on imagery was ambiguous because over the course of a 12 km transect, terrain is so variable to that it was not a simple matter to evaluate the time required for a typical crew to complete it. The remaining 81 anomalous transects were not reclassified, either because the classification still seems ambiguous, or because the crew's modification was based on access, illness, or considerations unrelated to terrain.

Proportion of each stratum walked

The proportion of each stratum walked in 2010 could be calculated based on the proportion of transects shortened and/or replaced (GBI) or based on the proportion of kilometers walked, based on the expectation that 12 km should be walked for each transect assigned (Kiva and IWS). In 2008 and 2009, only the previous method was used, and all transects assigned in 2010 had already been classified as 12k, 6k, or unwalkable. To test the comparability of estimating the unsampled part of each stratum, I calculated the number of kilometers expected to be walked based on the 12k/6k/unwalkable classification of each assigned transect, then compared this to the proportion of kilometers estimate (Table 9).

Table 9. Proportion of each stratum that can be sampled. Stratum abbreviations as in Fig. 1.

		Proportion assigned transects expected to be walked as…			Km walked		
Stratum	Assigned transects	12k	6k	Replaced	Expected	Observed	Chi-sq
AG	33	84.8	12.1	3	375	288.6	19.8
BD	66	60.6	30.3	9.1	600	590.5	0.1
CK	61	63.9	18	18	600	565.2	2.0
CM	40	77.5	7.5	15	417	377.2	3.8
CS	99	60.6	27.3	12.1	882	824.3	3.8
FE	20	100	0	0	240	233.5	0.2
FK	50	94	6	0	591	549.6	2.9
GB	128	48.4	35.2	16.4	1014	990.2	0.5
IV	30	86.7	0	13.3	324	305.1	1.1
JT	25	56	24	20	237	197.6	6.6
MM	130	53.1	39.2	7.7	1134	1091.5	1.6
OR	25	68	20	12	258	232.9	2.4
PI	44	70.5	18.2	11.4	459	417.5	3.8
PT	18	50	11.1	38.9	147	140.6	0.3
SC	109	89	6.4	4.6	1242	1202.9	1.2
Total	**878**				**8520**	**8007**	**50.1**
GBI	**423**				**3630**	**3496**	**6.1**
IWS	**134**				**1440**	**1333**	**8.9**
Kiva	**321**				**3449**	**3177**	**35.2**

Chi-squared values in the final column indicate a poor fit between predictions and completion at CMAGR, which is not surprising, given constraints on access to different parts of the range each year (crews frequently cannot get access to otherwise walkable transects, so these transects are replaced). With the exception of CMAGR, the strata individually and for each group combined indicate that the completed kilometers were accurately predicted regardless of method used to estimate unwalkable terrain.

This means we can use the observed kilometers walked to estimate the area over which our density estimates apply. For strata walked by GBI, we can use the proportion of transects classified as 12k/6k/unwalkable instead. Because this project uses the same base set of transects each year, the majority of transects have been walked in multiple years. Table 9 demonstrates that the 2 methods of estimating the proportion of area sampled are equivalent, so we can develop a more representative estimate of the walkable area of these strata if we use empirical data from all transects walked between 2008 and 2011 (the latest set of compiled data). Since 2008, 2464 separate transects have been evaluated in these strata; this is a much larger (representative) sample than the 878 evaluated only in 2010. Table 10 gives the area of each stratum, the proportion covered by our density estimates, and converts the density in each stratum into an estimate of tortoise abundance.

Table 10. Estimated tortoise abundance in sampled areas of each stratum. The "proportion sampled" column is based on evaluation of all transects in the sample set from 2008 through 2011. Stratum abbreviations as in Fig. 1.

Stratum	Area (km^2)	Proportion sampled	SE(Prop. Sampled)	Sampled area (km^2)	N (number of tortoises)	95% Confidence Interval	
						Lower Limit	Upper Limit
AG	755	0.95	0.024	715	9863	6005.8	16197.7
BD	828	0.89	0.032	738	2422	1401.3	4185.3
CK	3509	0.82	0.030	2890	10804	6007.7	19431.3
CM	4038	0.93	0.023	3755	15788	8336.2	29900.9
CS	1117	0.86	0.031	958	3471	2170.7	5551.4
FE	1862	0.96	0.020	1790	12419	6246.5	24691.1
FK	2462	0.96	0.017	2372	5869	3652.0	9431.8
GB	1977	0.81	0.027	1604	2782	1422.4	5441.0
IV	2567	0.95	0.021	2442	2476	1024.7	5980.6
JT	1567	0.74	0.033	1159	3197	1136.0	8996.3
MM	968	0.86	0.034	836	4624	3071.2	6962.8
OR	1124	0.73	0.040	821	6119	3749.8	9986.5
PI	2334	0.82	0.024	1911	5249	2773.3	9935.4
PT	751	0.69	0.051	522	1785	655.3	4863.4
SC	3332	0.95	0.015	3149	8276	5750.9	11910.2
Total	29190	0.879		24656	95145	77036.7	117510.7

Debriefing to identify strengths and weaknesses in preparation for future years

This meeting was held on 8 June, about 1 week after all field work was completed. The following issues were identified for coordinated effort rather than by efforts of single parties.

Need for more central responsibility for planning data

It was decided that starting in 2011, MDEP will host server-based [GIS] information for use by mapmakers. Through 2010, MDEP has provided Mojave-wide data layers to individual field teams, and assigned transects were identified by the UTM coordinates of their southwestern corners. Because there was little central oversight over how these data were acquired and used, different field teams had variable map quality and occasionally shifted transects when processing the corner coordinates into full square transects. This processing, including any planned shortening and/or reflections, should be repeatable each time the same transect is assigned, so centralized responsibility for this would be a better option.

Training improvements to make more effective use of same time period

In 2010, there were more trainees from more teams in the same areas for training at the same time. Use of the Desert Tortoise Conservation Center would be improved by setting up more stations (with more instructors) for smaller groups of trainees. Also, although objectives have been articulated for instructed material, this is not the case for the many days available for designated field practice. On those days, additional oversight and specific objectives that can be evaluated would improve effectiveness and provide additional feedback to crews.

Current hardware is less trustworthy and cannot utilize improved software

Since 2007, responsibility for providing the same data collection systems to all field teams has been centralized with the USFWS. Those units (data collection systems including connected GPS) are now outdated and will be replaced under advisement from MDEP and UNR.

Not all QA/QC errors remedied by the end of field season

Two types of errors occurred during the field season and were not corrected effectively. This resulted in 7 of the 888 transects inadvertently being walked twice and in different types of first-level QA/QC reporting errors from the 2 different data specialists. Although they were trained together by UNR, their approaches seemed to diverge as they addressed data errors. In 2011, the “end-user” (Topoworks) will spend more time training specialists. This work will also emphasize steps to take to avoid duplicating effort on any transects.

DISCUSSION

Sampling representatively in all monitoring strata

Since 2007, transects have been placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, yet the random aspect of this design also allows inference about the entire sampled area. Because the same set of potential transect locations will be used to sample from in future years, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years.

The current sampling design allows us to 1) estimate the actual area to which our density estimates apply; some areas are too rugged for humans to access, and therefore 2) apply the density estimate to this sampled area to arrive at an abundance estimate in each monitoring stratum.

Training developments

Training has received focused attention each year. This training improves the performance of individual crews, but also helps to standardize the application of protocols among different field teams. In 2010, experienced crew personnel worked with new trainees in their own and in different teams to add a new level of cohesiveness between field teams. This attention to standardized procedures is maintained during the field season, with frequent, customized, written crew evaluations, and we attribute continued high performance in 2010 directly to this focus on standardized training and implementation of protocols. No correction for failure to detect visible tortoises on the centerline have been made to density estimates since 2004 (prior to that, a 3-pass method was used to ensure all tortoises were detected). Training data in 2010 indicate that crews were detecting all tortoise models on the testing centerline, and by the end of training, first-year crews were performing as well as experienced crews.

Improving ability to detect trends in desert tortoise abundance

The primary goal of the monitoring program is to provide population estimates that are relevant to the recovery plan criteria (USFWS, 2011). The related priority is therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

There were new and enhanced funding sources in 2010, so that all strata had more than the minimum number of transects. Associated with the relatively high estimates of tortoise visibility (G_0), more tortoises were seen in some recovery units, even accounting for the enhanced level of effort. Whereas funding opportunities are under agency control, the particularly mild spring season also contributed to improved density estimates in most of the range. The notable exception was the Eastern Mojave/Northern Colorado, where the number of funded transects was still below optimal and the spring weather was cooler than optimal for tortoises to be out and visible most of the time. In the remaining 3 monitored recovery units, the coefficient of variation for density estimates was between 15 and 20% of the density estimate – reflecting an extremely successful field season. The Eastern Mojave/Northern Colorado recovery units had density estimates with lower precision (CV=29.5 and 33.4%, respectively), a reminder that insufficient funding and unseasonable conditions can act separately to thwart our coordinated efforts for range-wide density estimates.

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